UNDERWATER SYSTEMS, INC.

SPECTRAL ANALYSIS OF HYDROACOUSTIC SIGNALS
GENERATED BY THE CHASE EXPLOSIONS
TECHNICAL PROGRESS REPORT NO. 9

SPONSORED BY:
ADVANCED RESEARCH PROJECTS AGENCY (ARPA)
OFFICE OF NAVAL RESEARCH (ONR)

Contract No. NOnr 4026(00)
Project Code No. 3810
ARPA Order No. 218

December 23, 1965

World Building • 8121 Georgia Ave.
SILVER SPRING, MD. 20910
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SPECTRAL ANALYSIS OF HYDROACOUSTIC SIGNALS
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Introduction

Ref. (a) reports on spectrogram analysis of the hydroacoustic signals received at Bermuda and generated by the Chase explosions. Copies of the magnetic tape recordings were forwarded to Underwater Systems, Inc. for tape loop analysis. This report presents typical results from that analysis.

Analysis Procedure

The analysis is performed by transferring the signal of interest to a tape loop which is analyzed by a Panoramic Singer Metrics analyzer. In a typical analysis procedure a tape speed up of 16:1 is used and approximately 30 seconds of signal is analyzed. The analyzer will continuously sweep down from 200 cps to zero cps over a time interval of one-half hour. The loop is played back continuously, filtered in a 2 cps band, and the db level determined. This signal is then fed into an integrator whose integration time is controlled by a timing signal recorded on an adjacent tape channel. Integration begins when the portion of the signal of interest is reached and the integrator is dumped when it ends. This cycle is repeated for each tape loop playback. The integrator output is displayed graphically. Each line in the spectral charts presented here represents a single loop analysis.

By virtue of the tape speed up, the analysis corresponds to 0 - 12.5 cps with a band width of 1/8 cps. The analysis band is modified slightly by the continuous sweep of the analyzer,

but this amounts to only a fraction of the band width.

Since the analyzer takes the integral of the log rather than the log of the integral of voltage squared, level calibration is somewhat difficult. These levels are also dependent upon the integration time, which, for this analysis, was different for each loop. The data presented here should therefore be examined for spectral content only, and absolute levels are not presented.

Chase II - USS VILLAGE

Figs. (1) to (4) show the results for the Chase II explosion for the following conditions:

Fig. (1). Direct Signal

Fig. (2). Reverberation - 30 Seconds Later.

Fig. (3). Reverberation - About 11 Minutes Later.

Fig. (4). Reverberation - About 17 Minutes Later.

The bubble pulse frequency can be read from any one of these figures. However, Fig. (2) provides the clearest presentation. The bubble pulse frequency of 2.75 cps reported by the Bermuda Station is consistent with these results.

Chase III - COASTAL MARINER

Figs. (5) to (7) show the results for Chase III under the following conditions.

Fig. (5). Direct Signal.

Fig. (6). Reverberation - About 30 Seconds Later.

Fig. (7). Reverberation - About 4 Minutes Later.

For this case the direct signal does not show a clear bubble pulse pattern. Fig. (6), the reverberation immediately

following the direct signal, gives the best presentation. It should be noted that in Fig. (7) the maxima can be observed throughout the record. The bubble pulse frequency of 0.65 cps reported by Bermuda is identical with our results.

Chase IV - SANTIAGO IGLESIAS

The results of Chase IV are not as easily interpreted as those from Chase II and III. Typical spectra are shown in Figs. (8) to (10) for the following conditions.

Fig. (8). Direct Signal.

Fig. (9). Reverberation - About 30 Seconds Later.

Fig. (10). Reverberation - About 20 Minutes Later.

Bermuda has reported a bubble frequency of 0.8 cps which is consistent with these results. Again, the bubble pulse frequency can not be read from the direct arrival. Fig. (9) does not show the maxima as clearly as the comparable results for Chase II and Chase III. From Fig. (10) one can easily observe a bubble pulse frequency of about 0.80 cps.

The spectral characteristics of Fig. (9) have been examined more closely. In addition to a series of maxima with fundamental of about 0.83 cps other maxima exist. In discussions with G. Hamilton, Columbia University Geophysical Field Station, Bermuda, he has pointed out that based on the migration theory of Dr. Snay, the conditions for Chase IV would result in approximately equal energy levels for the 1st and 2nd bubble pulse and the periods would be almost equal. For this condition fundamental frequencies of about equal strength would exist at $1/\tau_1$, $1/\tau_2$, and $1/(\tau_1+ \tau_2)$. The resultant spectrum would then be considerably more complex. For comparison, Fig. (11) shows

the spectrum for a signal consisting of three exponentially decaying signals of equal amplitude spaced at $\tau = 0$, 1.0 seconds, 1.8 seconds. The gross similarity between Figs. (9) and (11) should be noted.

Reverberation Losses

It is noted from Figs. (1) to (4) that the low frequency energy distribution is a function of time after the direct arrival. The first maxima has the highest energy for Figs. (1) and (2). For Figs. (3) and (4) the third and fourth maxima have maximum energy. For Chase III similar results are obtained with the third and fourth maxima of about equal levels for Fig. (6) and the eighth to twelfth for Fig. (7). Similar shifting in energy distribution is also observed in Chase IV (Figs. (9) and (10)). This effect is believed to be the result of shallow water propagation effects. Ref. (b) gives the limiting wave length λ, above which mode transmission does not take place, as:

$$\lambda = 4\ H \sqrt{1-(c_1/c_2)^2}$$

where: c_1, c_2 is the sound velocity in water and the bottom respectively.

H is the water depth.

Typical values for bottom sound velocity yield:

$$\lambda \approx 2\ H$$

The Chase III and Chase IV explosions took place in 5,000 feet of water and reverberation for the East Coast required propagation into very shoal water. The area available for bottom reverberation at low frequencies would then depend upon water depth, shelf slope and wave length. On this basis one can

make some broad brush predictions concerning the low frequency energy in the reverberant signal.

a). Reverberation from the East Coast should show reduced levels at low frequencies.

b). Reverberation from coast lines should show good signals at the low frequencies when the bottom drops rapidly to great depth off shore. The West Indies region is a good example.

To examine these predictions the Chase III data was analyzed in 1/8 cps bands in real time as shown in Fig. (12) to (28). The level for the direct signal is affected by overload for the first 30 seconds of record and should be discounted.

As can be noted the reverberant levels generally increase with frequency as expected. The fluctuation for adjacent bands reflects the effect of bubble pulse frequency. To further indicate the reduction in reverberant energy at the very low frequencies the signal was examined in the following bands:

Fig. (29). 0 - 3 1/8 cps

Fig. (30). 3 1/8 - 6 1/4 cps

Fig. (31). 6 1/4 - 9 3/8 cps

Fig. (32). 9 3/8 - 12 1/2 cps

As can be seen the reverberant energy increases from Fig. (29) to Fig. (30) to Fig. (31). About equal reverberant energy levels are indicated by Fig. (31) and (32).

The reverberant returns were examined for point of origin. At the low frequencies this corresponds to reflection from the West Indies Island chain. As can be noted from appropriate charts the off shore bottom drops rapidly to great depth.

Conclusion

The results of this analysis indicate that:

1. Loop analysis provides an exceedingly clear display of the bubble pulse frequency.

2. Reverberation rather than the direct signal should be analyzed. For Chase II and III the reverberation immediately following the direct signal gave excellent results.

3. For conditions under which the energy partition yields near equal levels for two or more bubble pulses the spectrum will be more complex. It may be possible to extract both the 1st and 2nd bubble pulse periods for such spectra but additional study is required before a firm conclusion can be reached.

4. The spectral distribution in the reverberant signal will depend upon the water depth and slope in the reverberant area. In particular, the very low frequencies will be lost when shoal water propagation is involved and will be present only for reverberant signals originating from areas where the water depth drops very rapidly off shore.

REFERENCES

(a) G. R. Hamilton and Brian Patterson, Spectra of Large Underwater Explosions (Abstract), J. Acoust. Soc. Am., 38, 941, Nov., 1965.

(b) C. L. Pekeris, Theory of Propagation of Explosive Sound in Shallow Water, Geological Society of America, Memoir 27, 1948.

FOR CHASE PROGRAM SOURCE DATA SEE:

Underwater Systems, Inc., Chase III Source Data, Technical Progress Report No. 7, August 23, 1965. Contract No. NOnr 4026(00).

Underwater Systems, Inc., Chase IV Source Data, Technical Progress Report No. 8, September 24, 1965. Contract No. NOnr 4026(00).

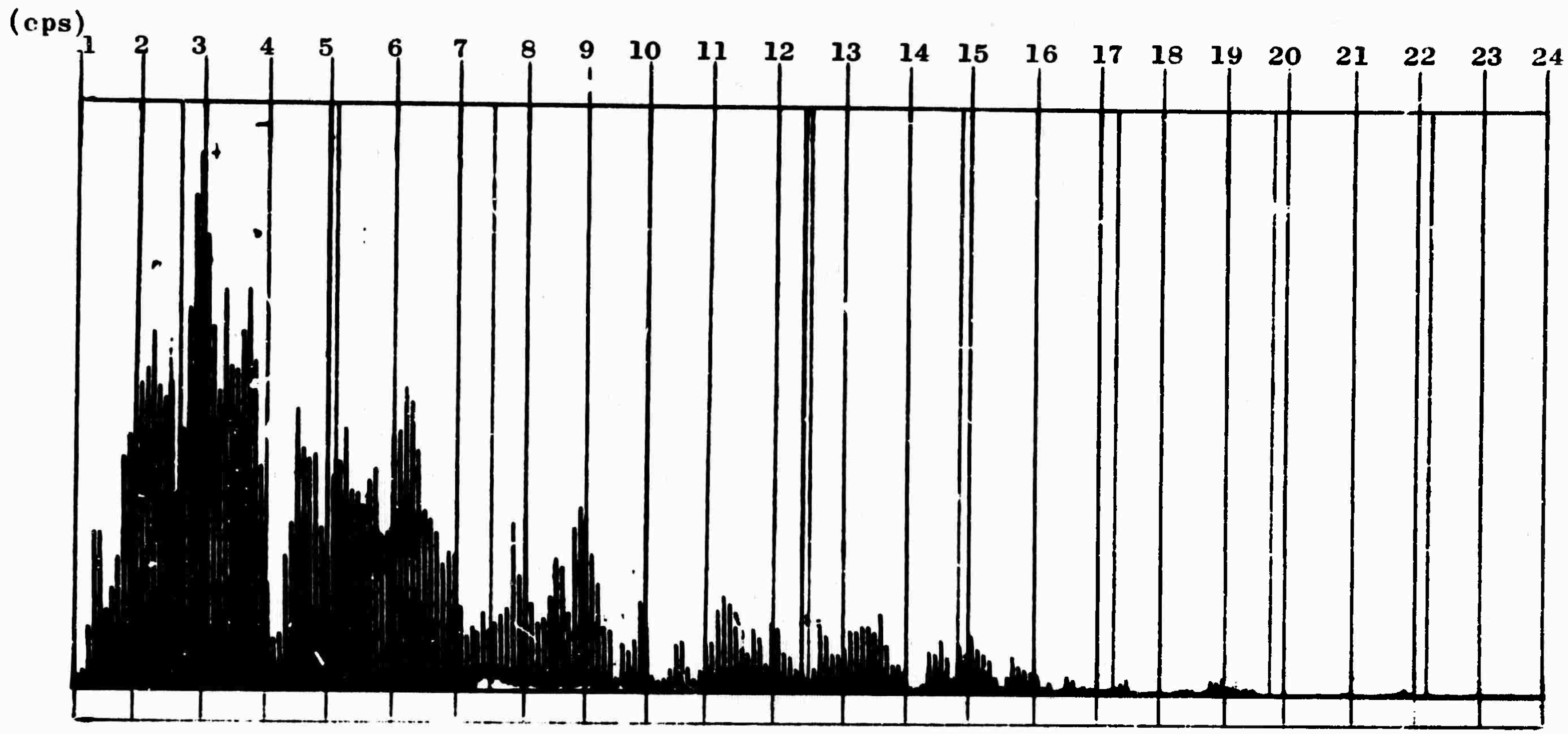


Fig. (1)
Spectral Density of Hydroaccustic Signal from USS VILLAGE Explosion.
Direct Signal.

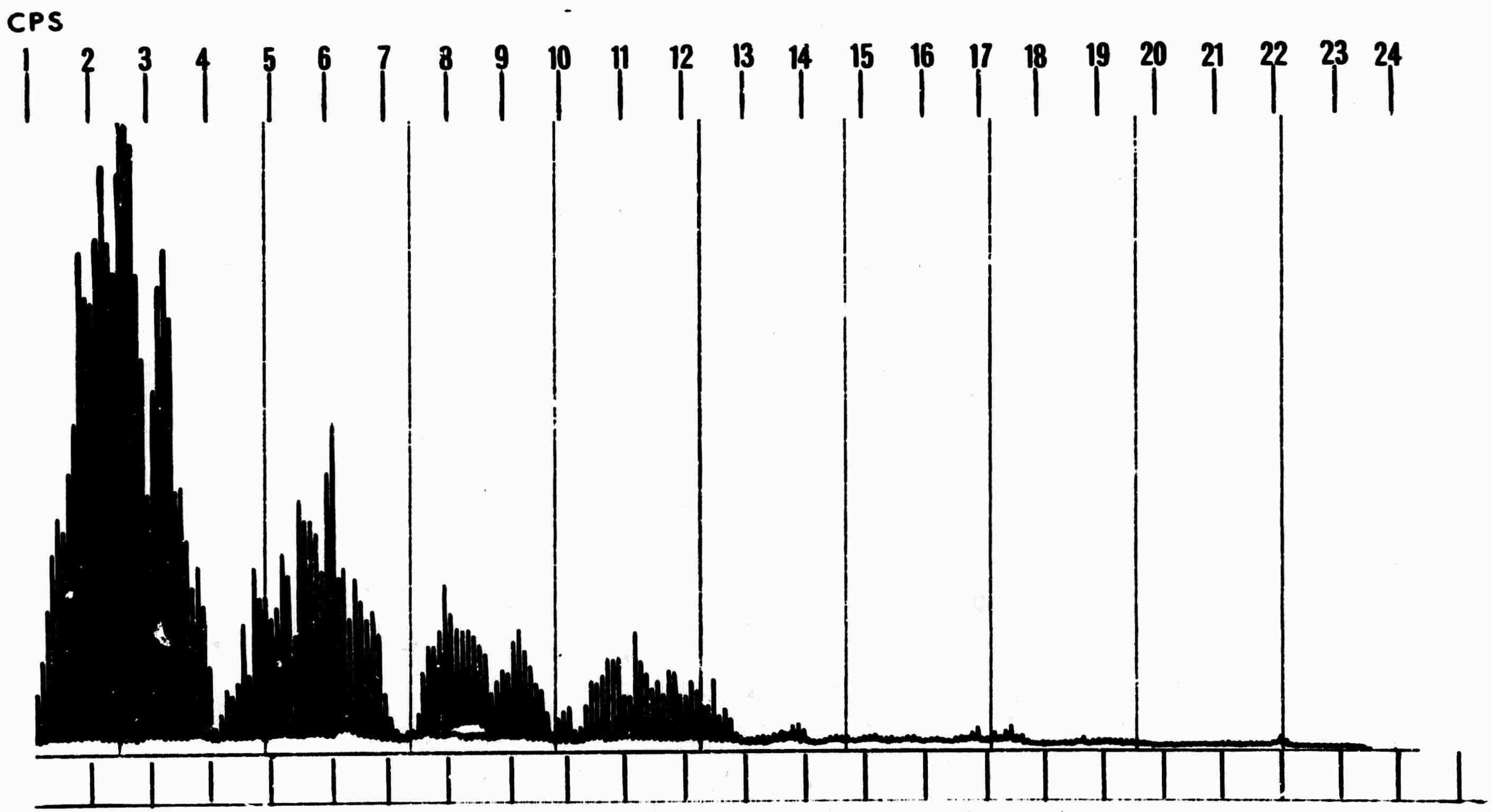


Fig. (2)
Spectral Density of Hydroacoustic Signal from USS VILLAGE Explosion.
Reverberation About 50 Seconds After Direct Arrival.

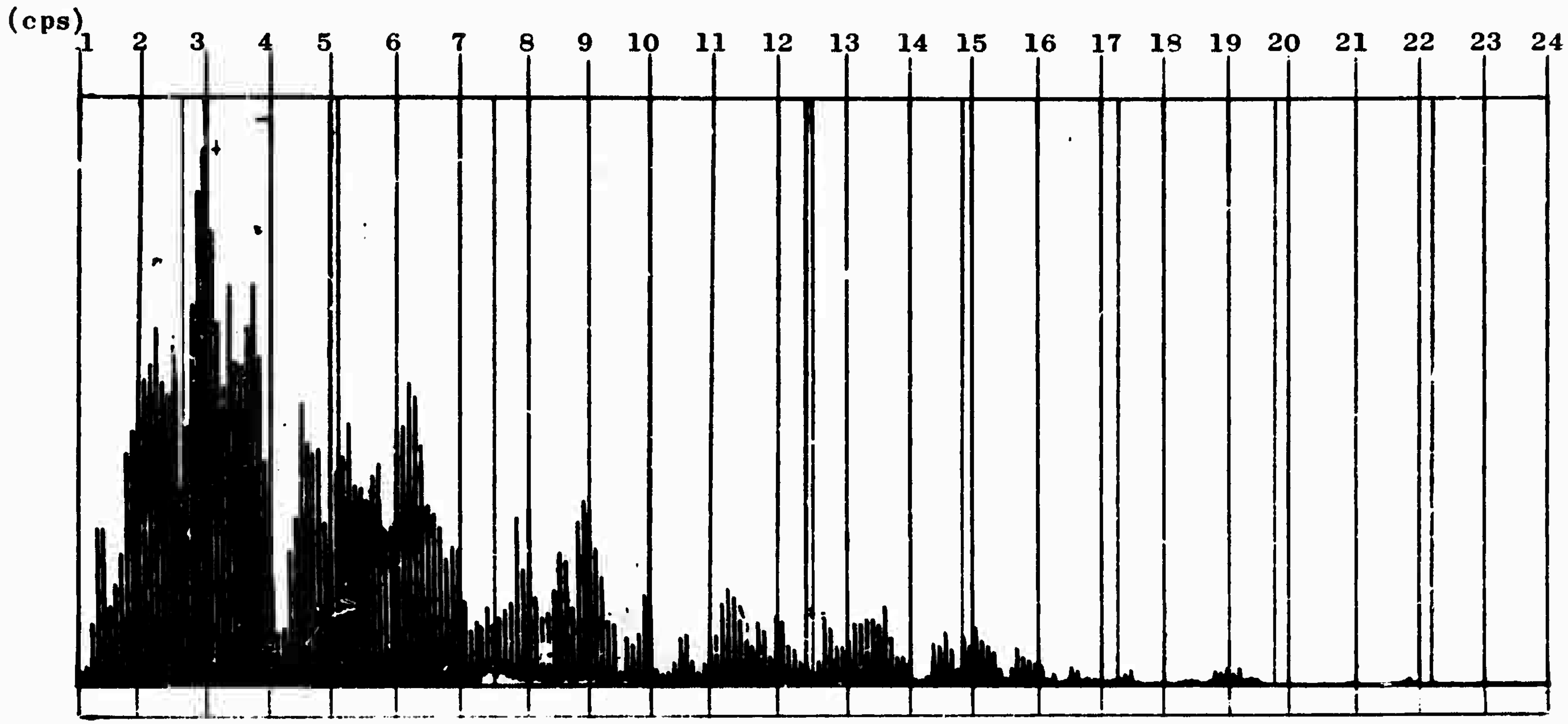


Fig. (1)
Spectral Density of Hydroacoustic Signal from USS VILLAGE Explosion.
Direct Signal.

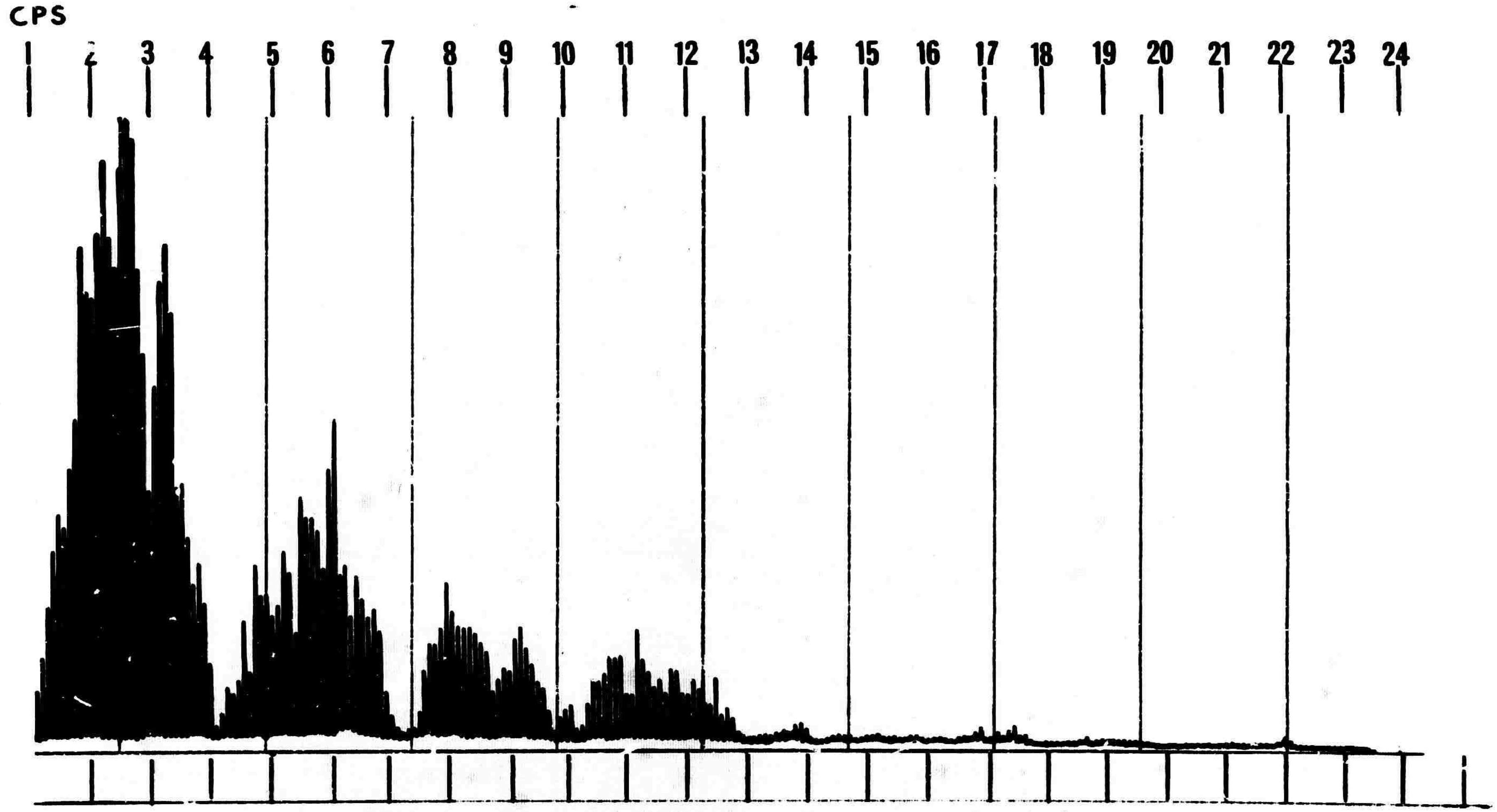


Fig. (2)
Spectral Density of Hydroacoustic Signal from USS VILLAGE Explosion.
Reverberation About 30 Seconds After Direct Arrival.

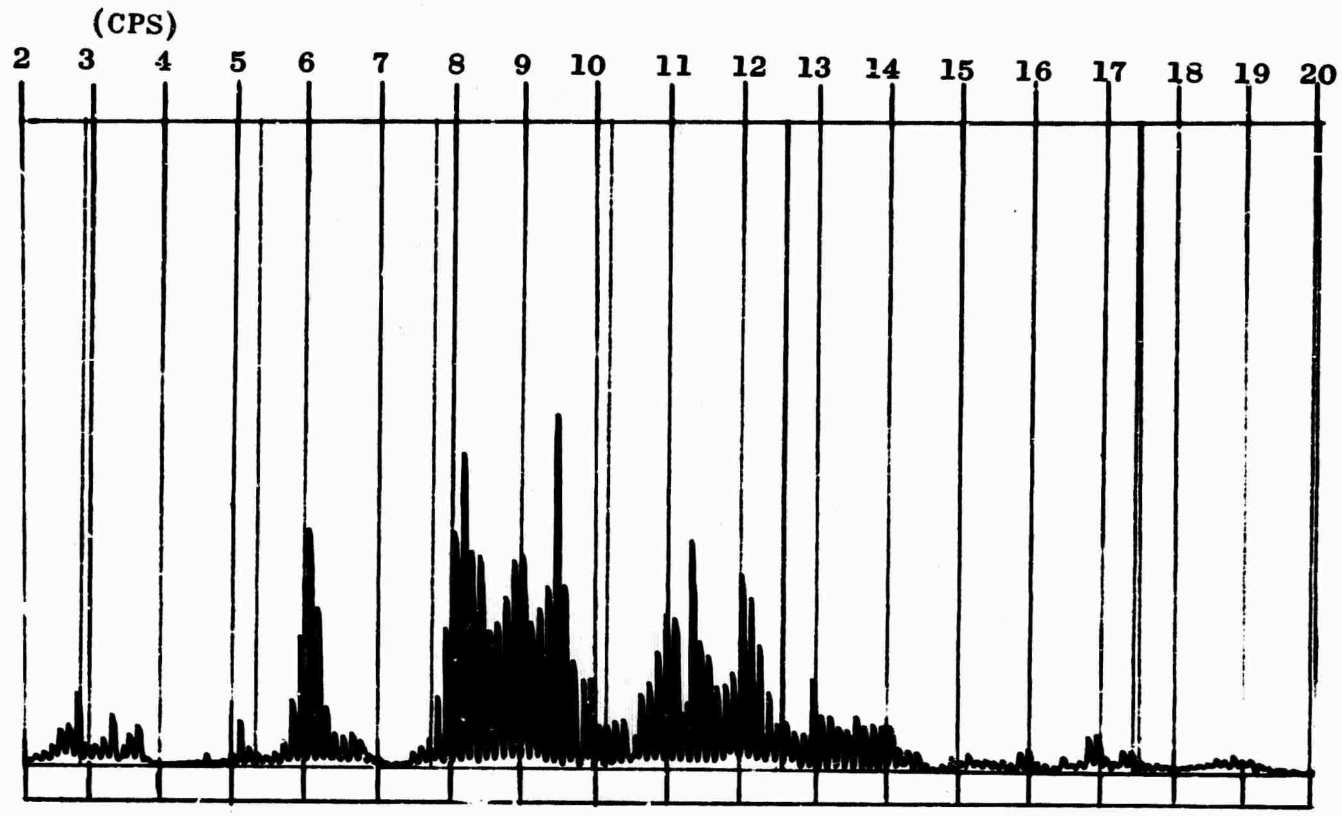


Fig. (3)
Spectral Density of Hydroacoustic Signal from USS VILLAGE Explosion.
Reverberation About 11 Minutes After Direct Arrival.

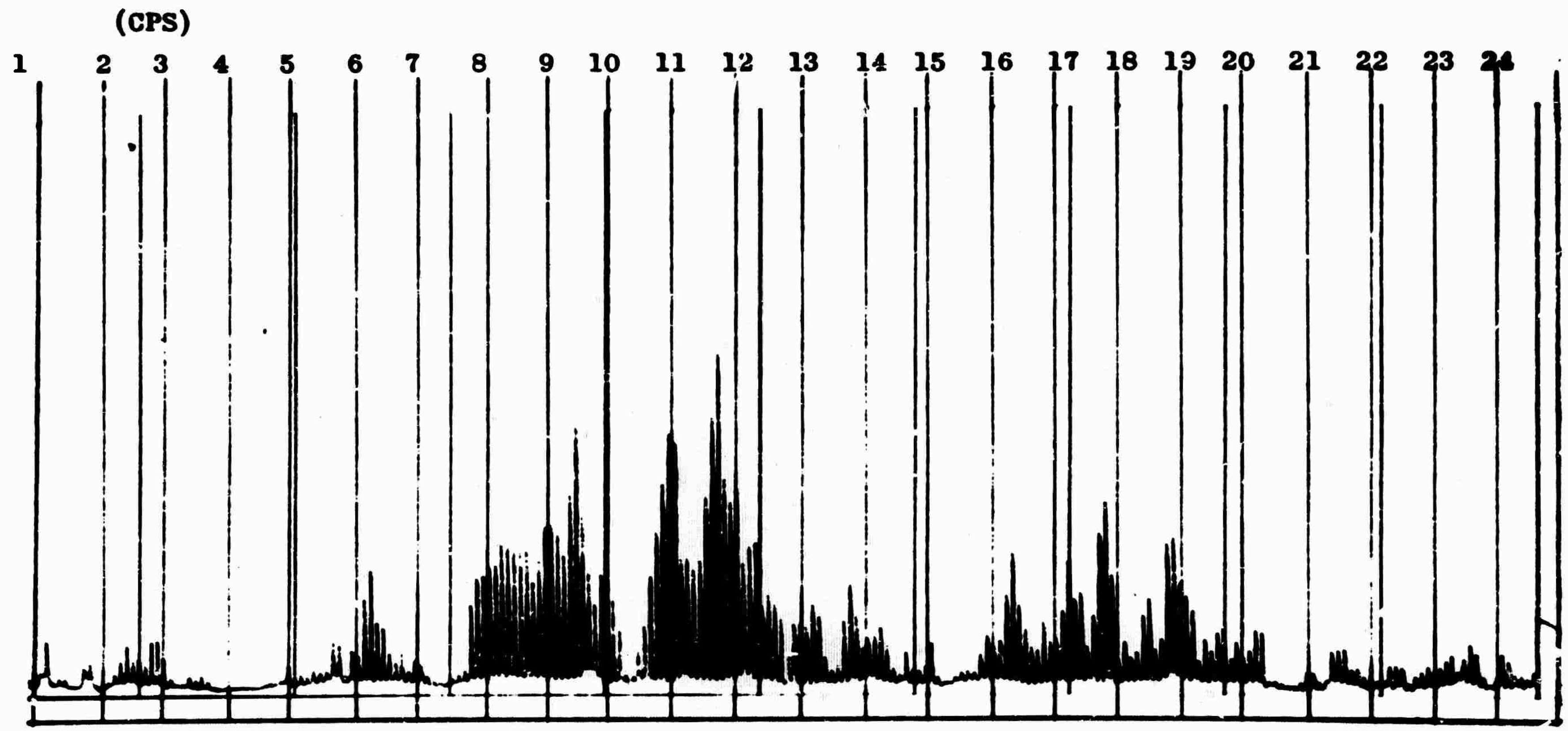


Fig. (4)
Spectral Density of Hydroacoustic Signal from USS VILLAGE Explosion.
Reverberation About 17 Minutes After Direct Arrival.

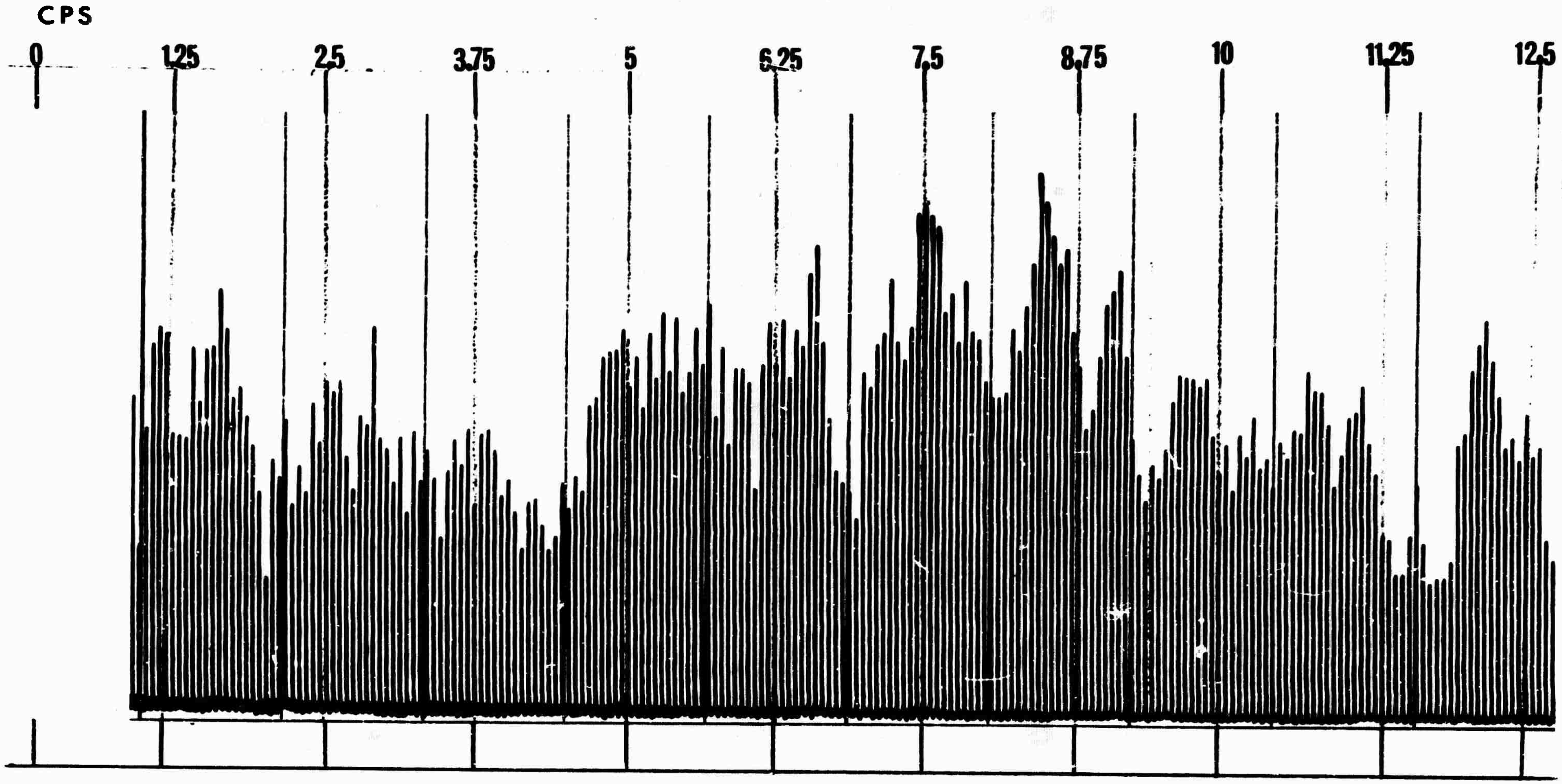


Fig. (5)

Spectral Density of Hydroacoustic Signal from Coastal Mariner Explosion.
Direct Signal.

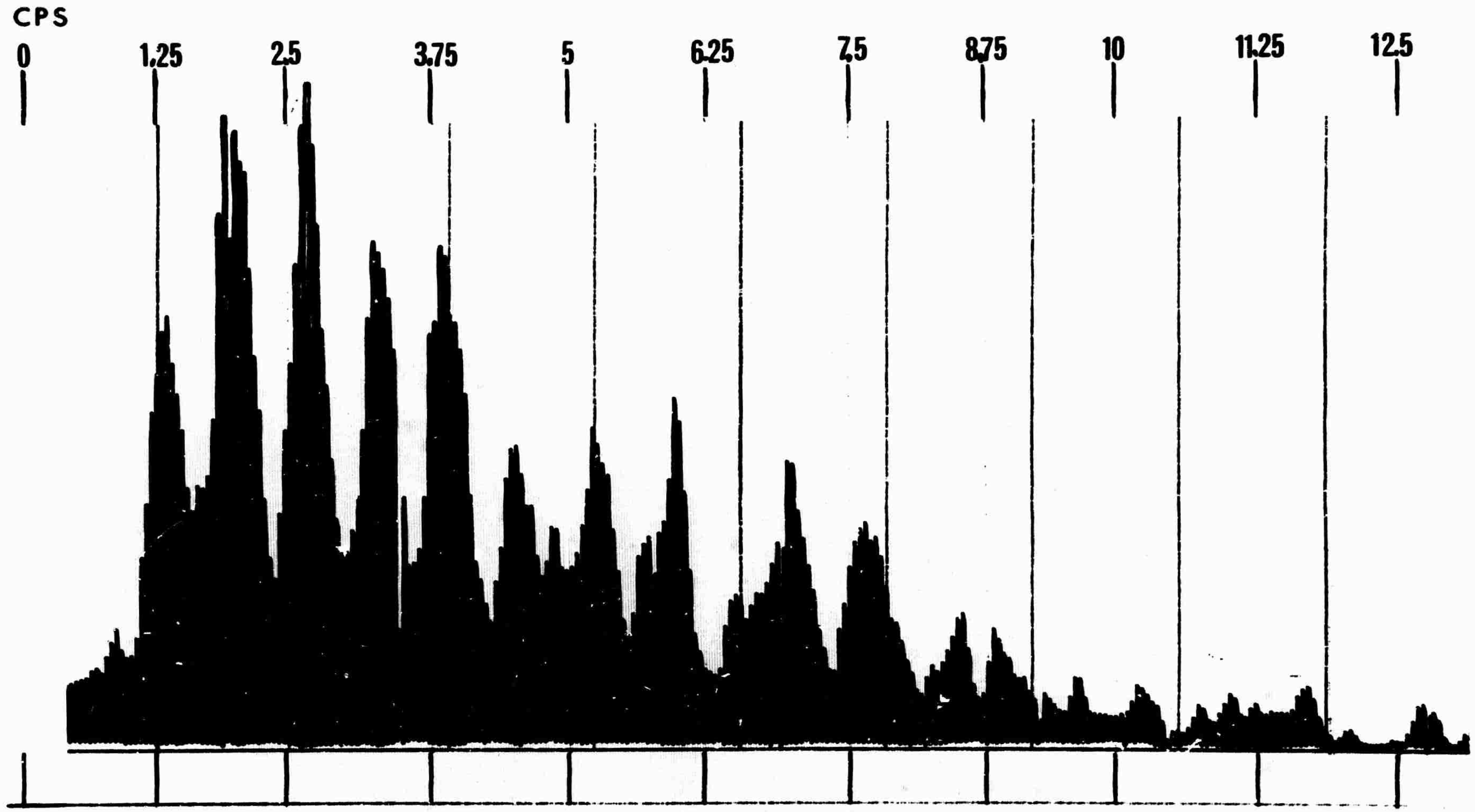


Fig. (6)
Spectral Density of Hydroacoustic Signal from Coastal Mariner Explosion.
Reverberation About 30 Seconds After Direct Arrival.

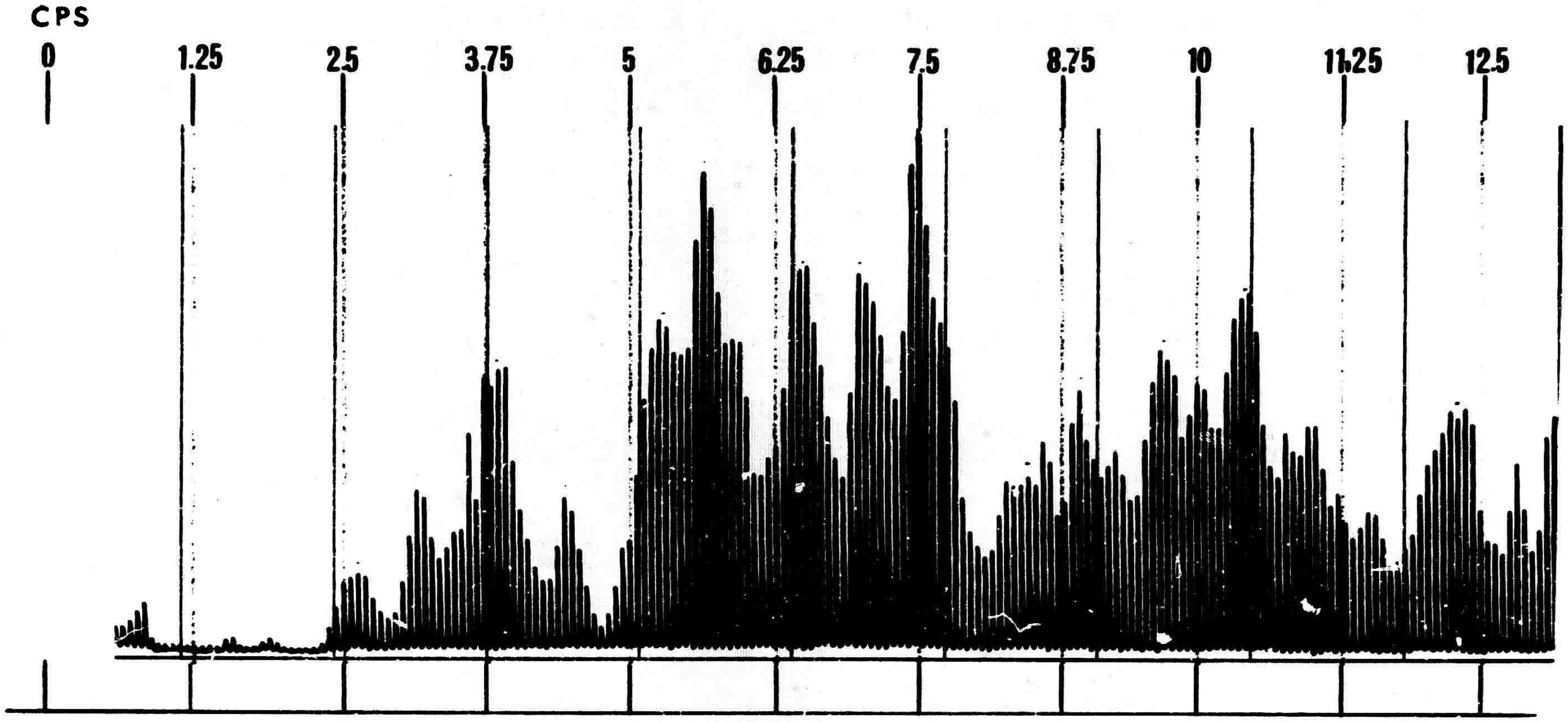


Fig. (7)
Spectral Density of Hydroacoustic Signal from Coastal Mariner Explosion.
Reverberation About 4 Minutes After Direct Arrival.

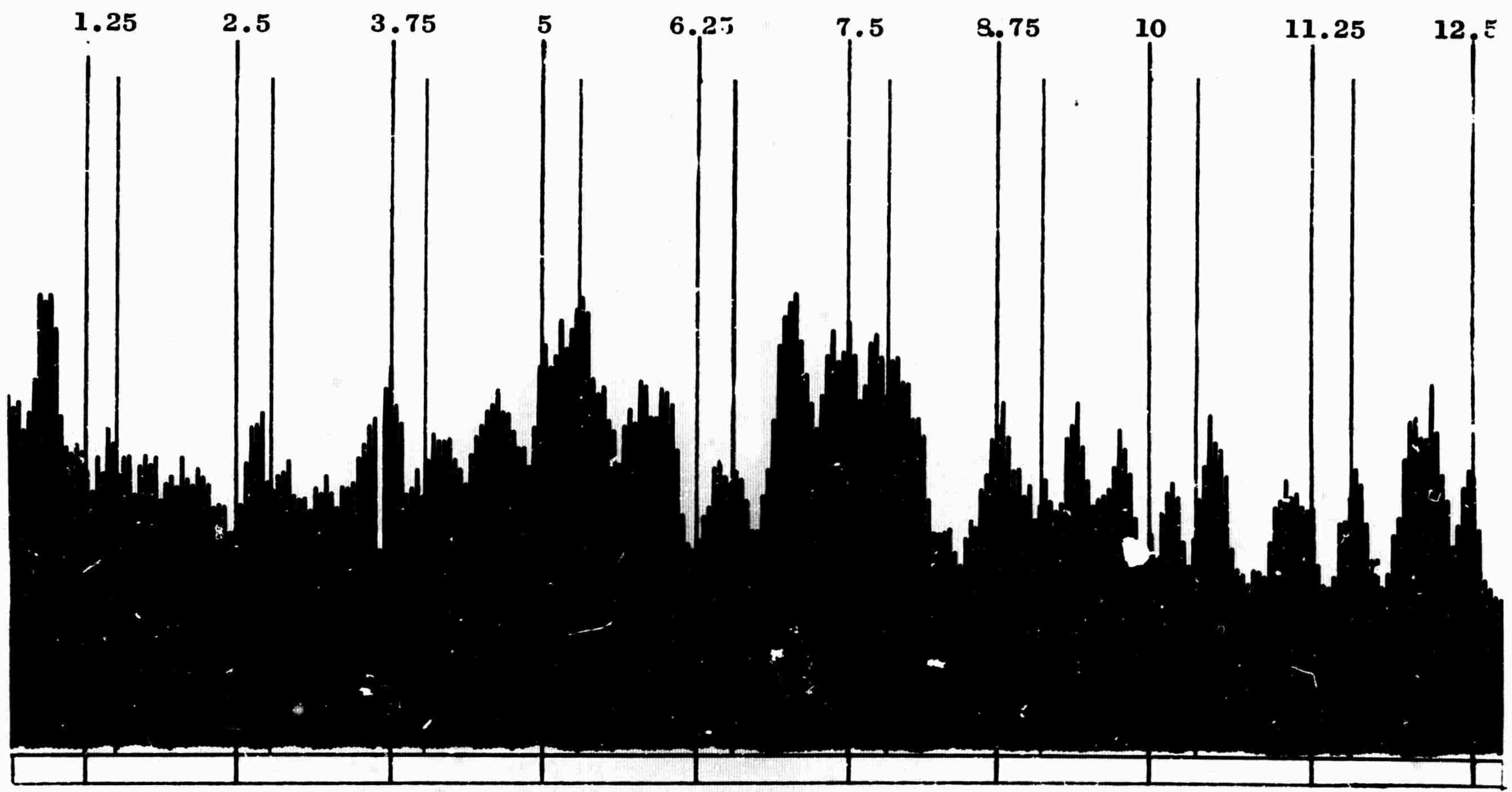


Fig. (8)
Spectral Density of Hydroacoustic Signal from SANTIAGO IGLESIAS.
Direct Signal.

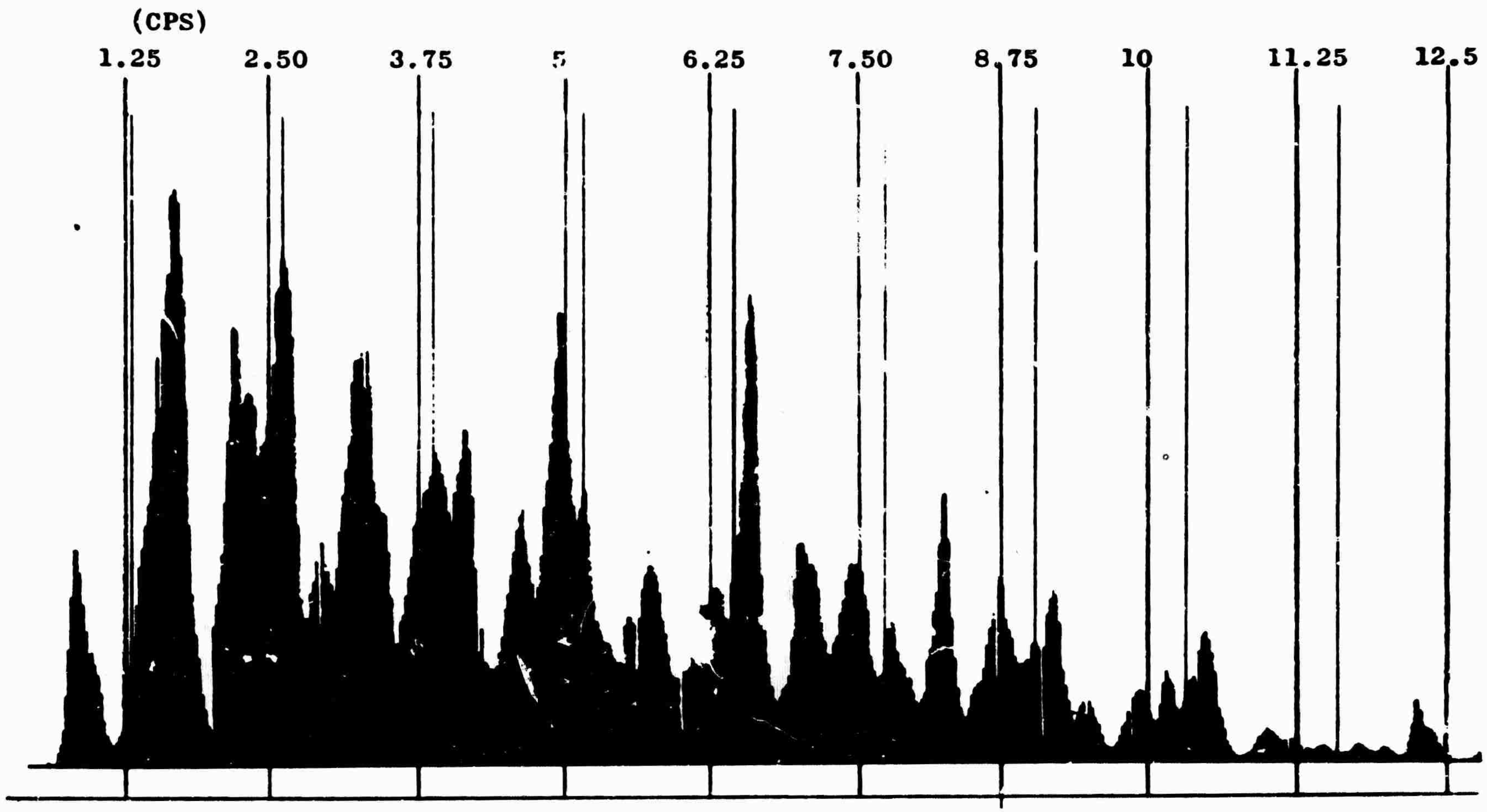


Fig. (9)
Spectral Density of Hydroacoustic Signal from SANTIAGO IGLESIAS.
Reverberation about 30 Seconds after Direct Arrival.

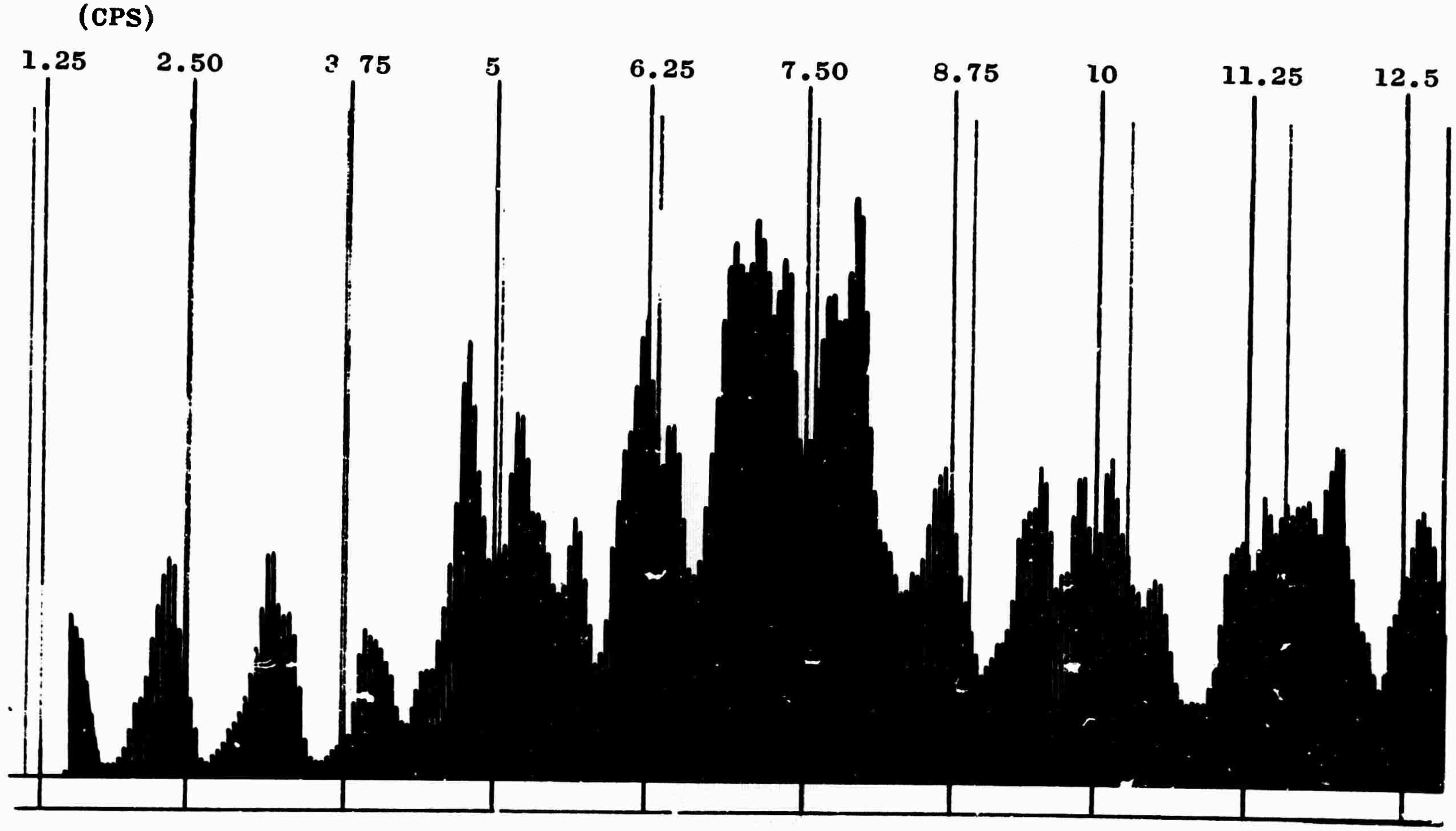


Fig. (10)
Spectral Density of Hydroacoustic Signal from SANTIAGO IGLESIAS.
Reverberation about 20 Minutes after Direct Arrival.

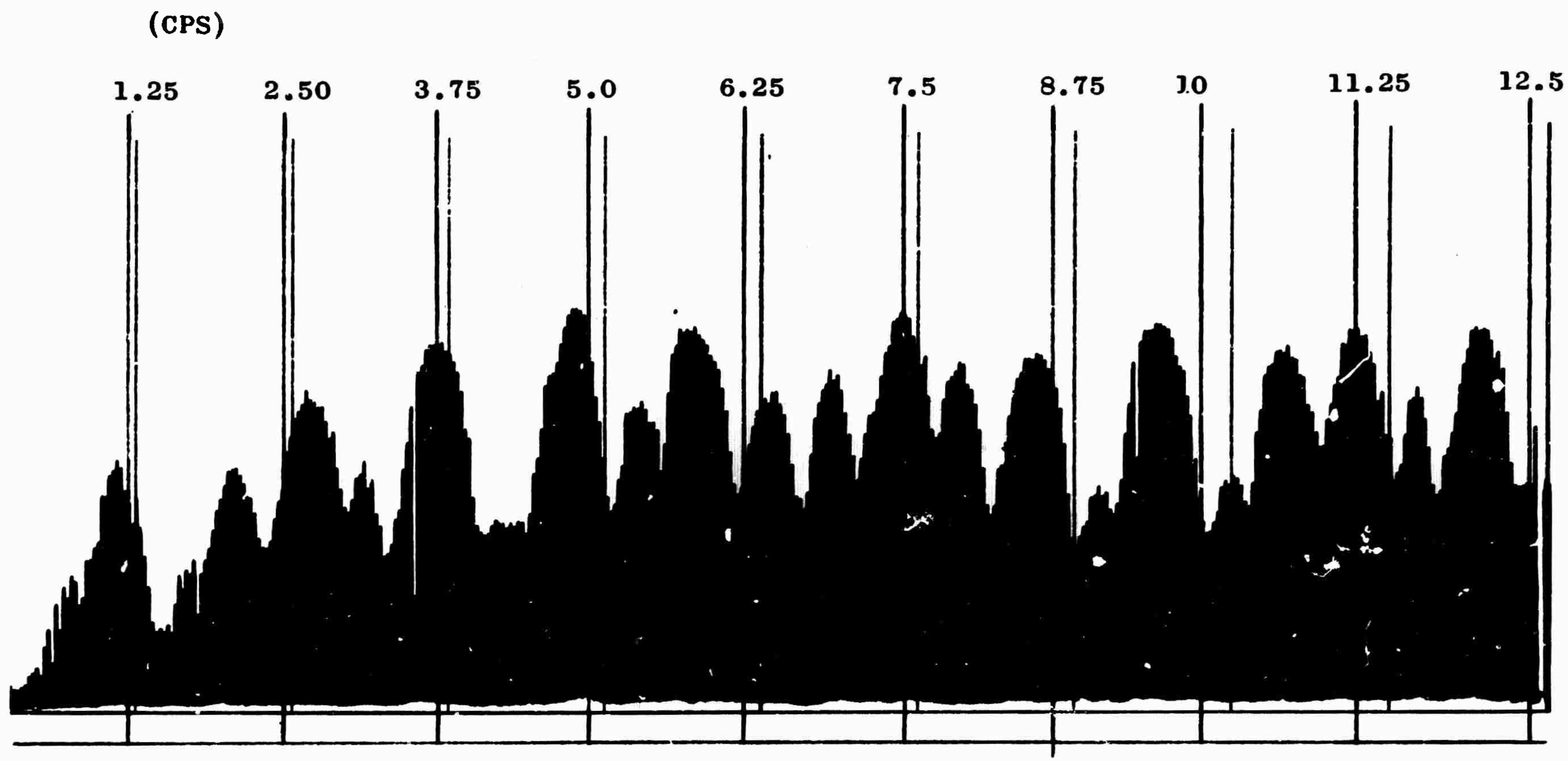


Fig. (11)
Spectral Density of Three Exponentially Decaying Pulses Spaced at τ = 0, 1.0 and 1.8 Seconds. Decay Constant 10 Milliseconds.

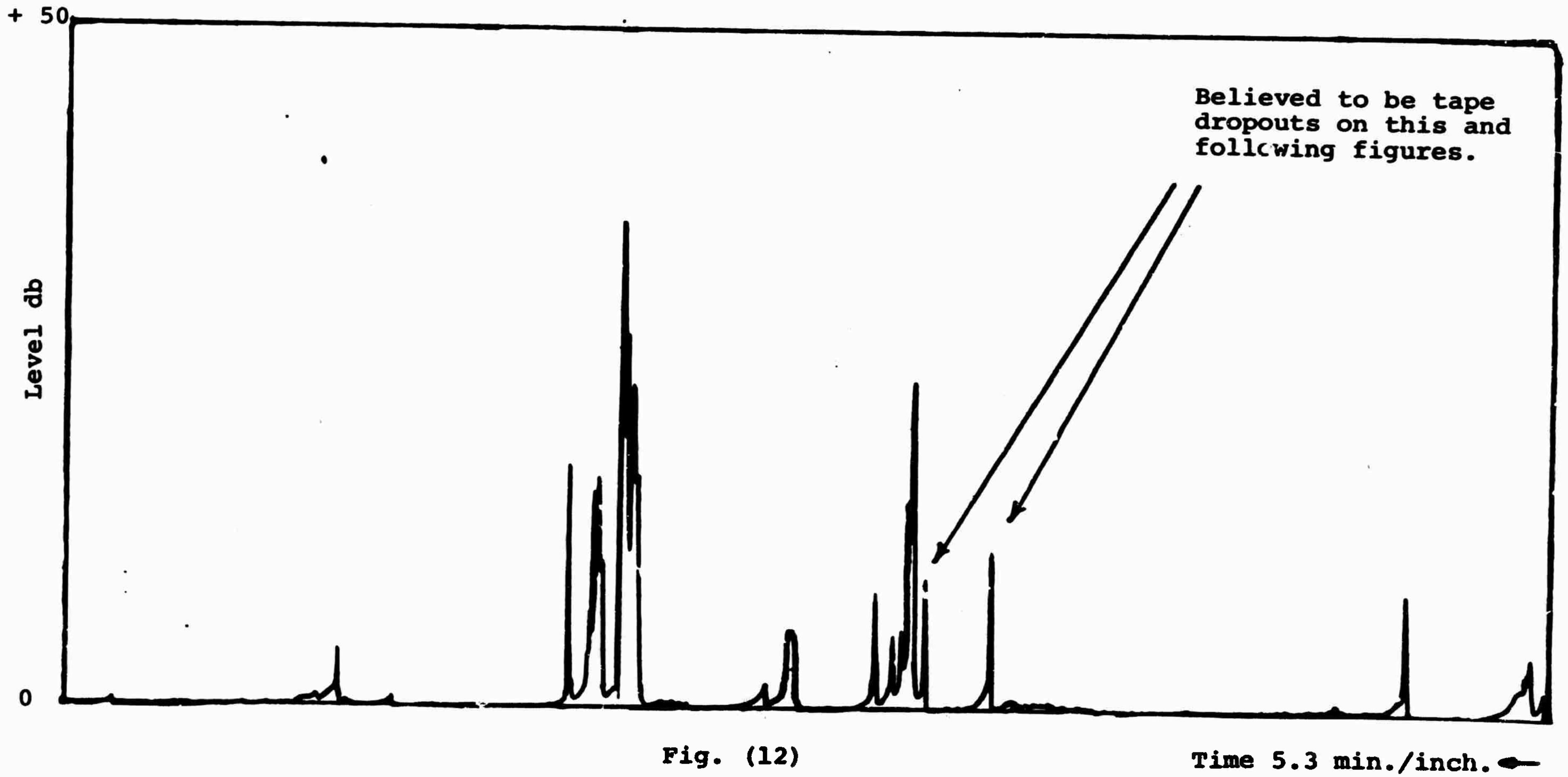


Fig. (12)
Coastal Mariner energy level vs. time.
Center frequency 5/8 cps. Band width 1/8 cps.

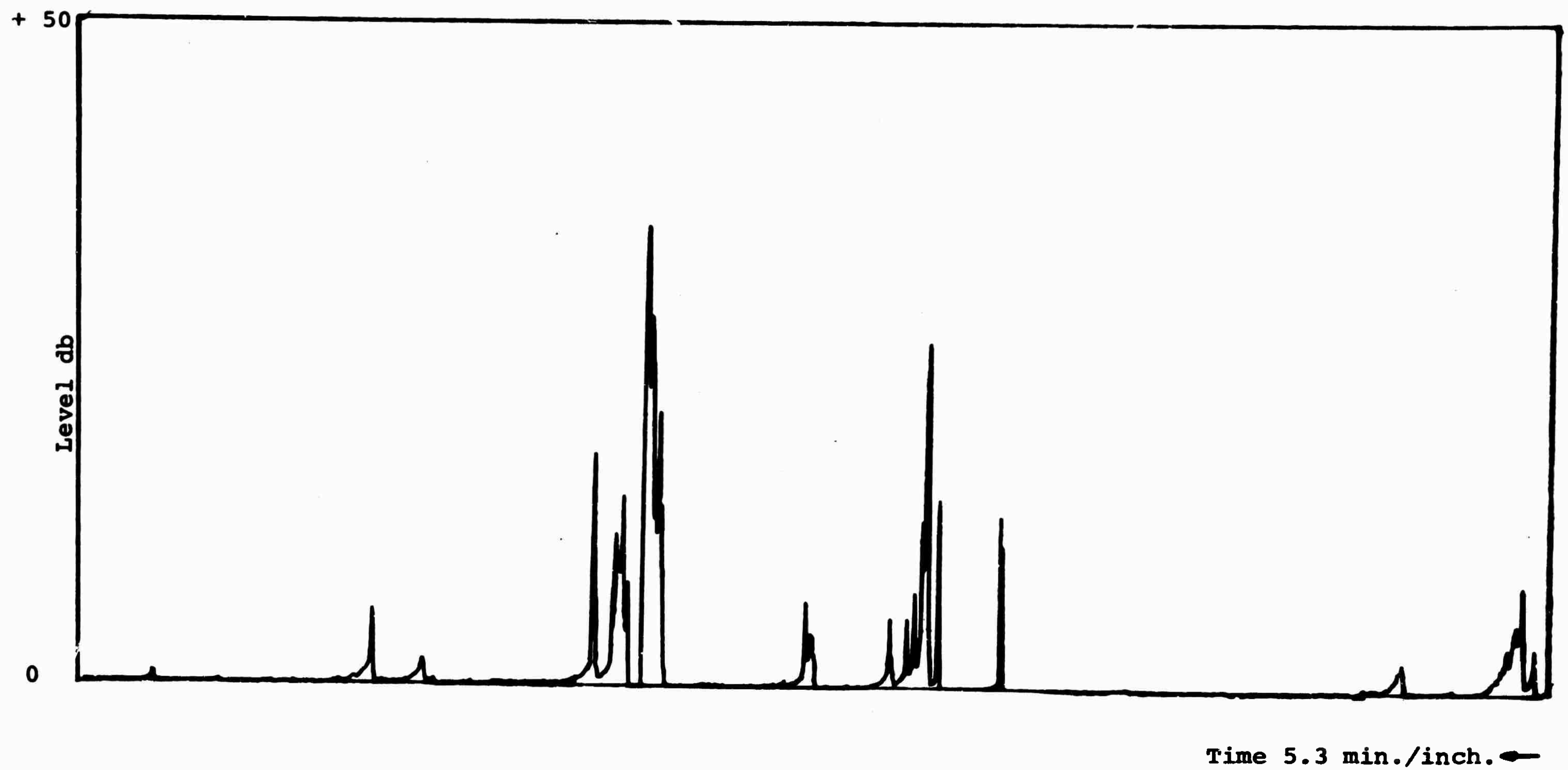


Fig. (13)

Coastal Mariner energy level vs. time.
Center frequency 6/8 cps. Band width 1/8 cps.

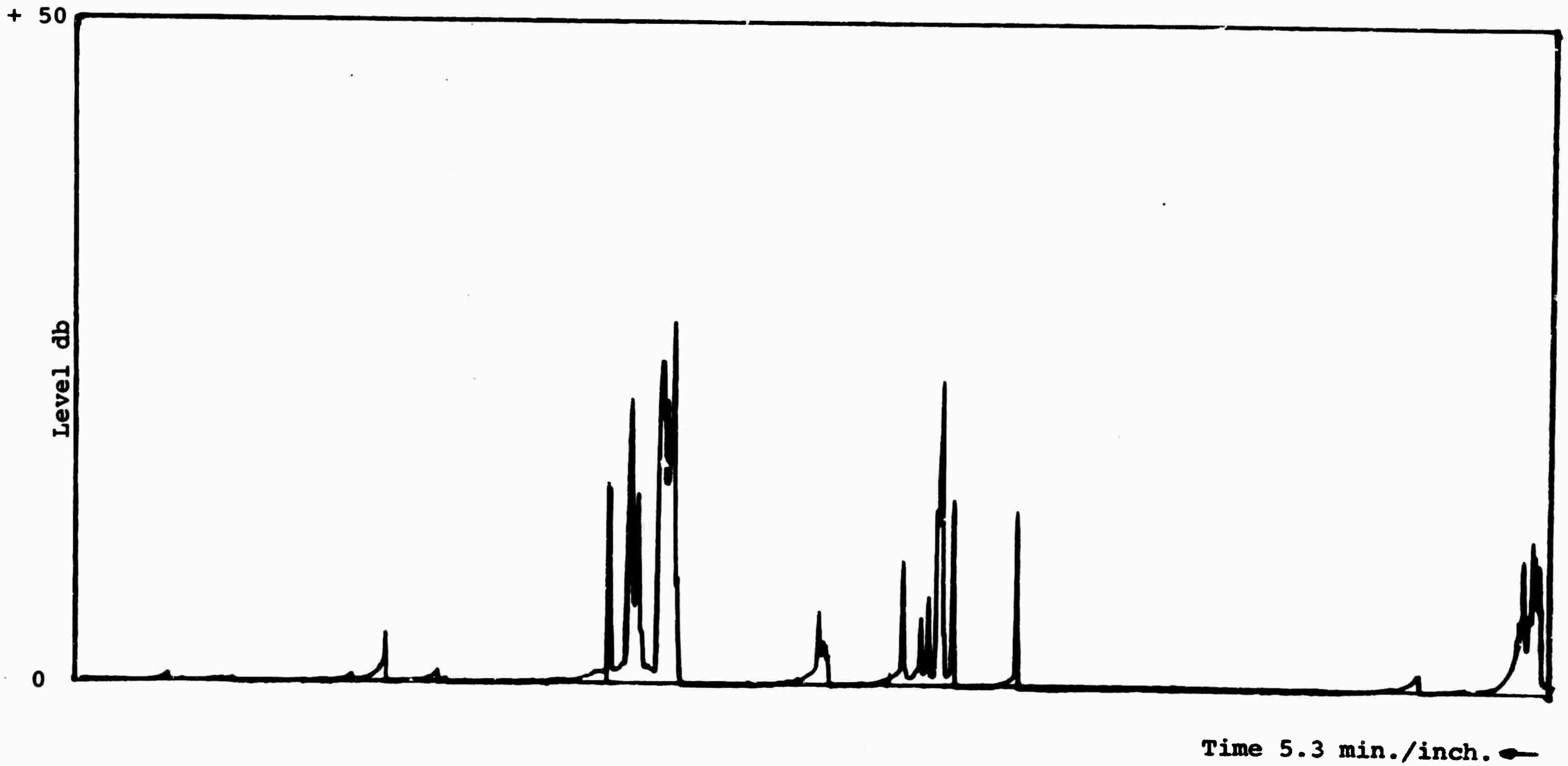


Fig. (14)
Coastal Mariner energy level vs. time.
Center frequency 7/8 cps. Band width 1/8 cps.

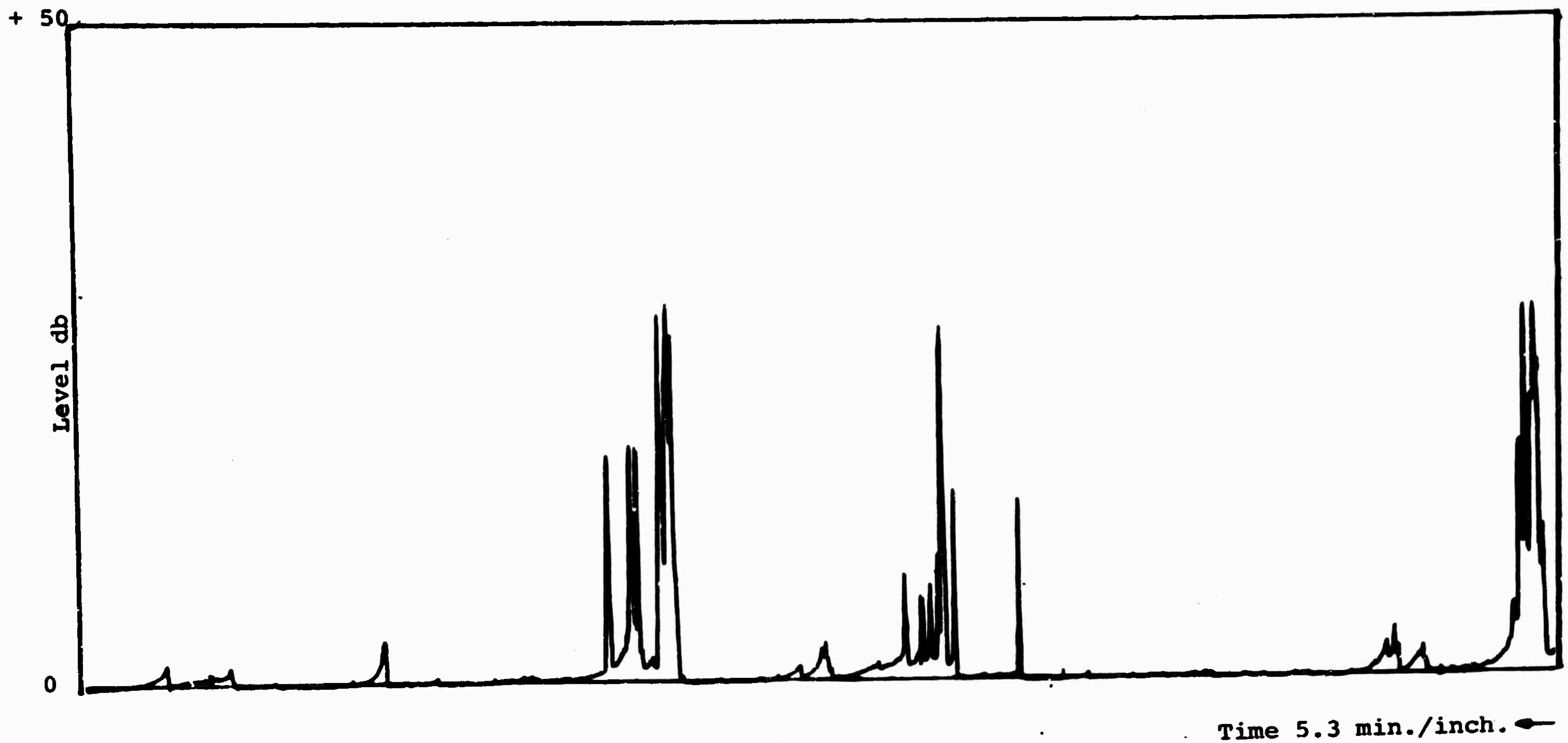


Fig. (15)
Coastal Mariner energy level vs. time.
Center frequency 1 cps. Band width 1/8 cps.

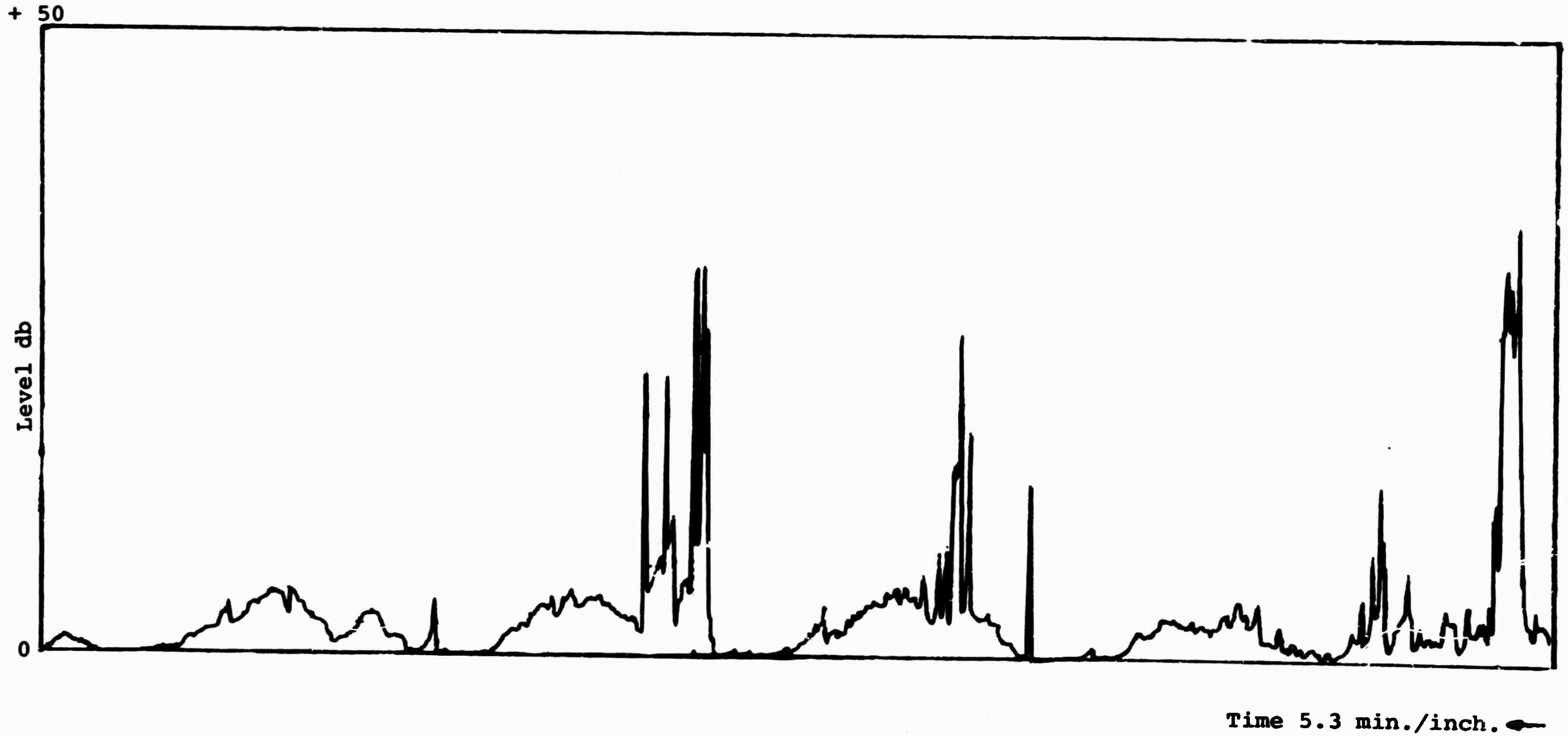


Fig. (16)
Coastal Mariner energy level vs. time.
Center frequency 1 1/8 cps. Band width 1/8 cps.

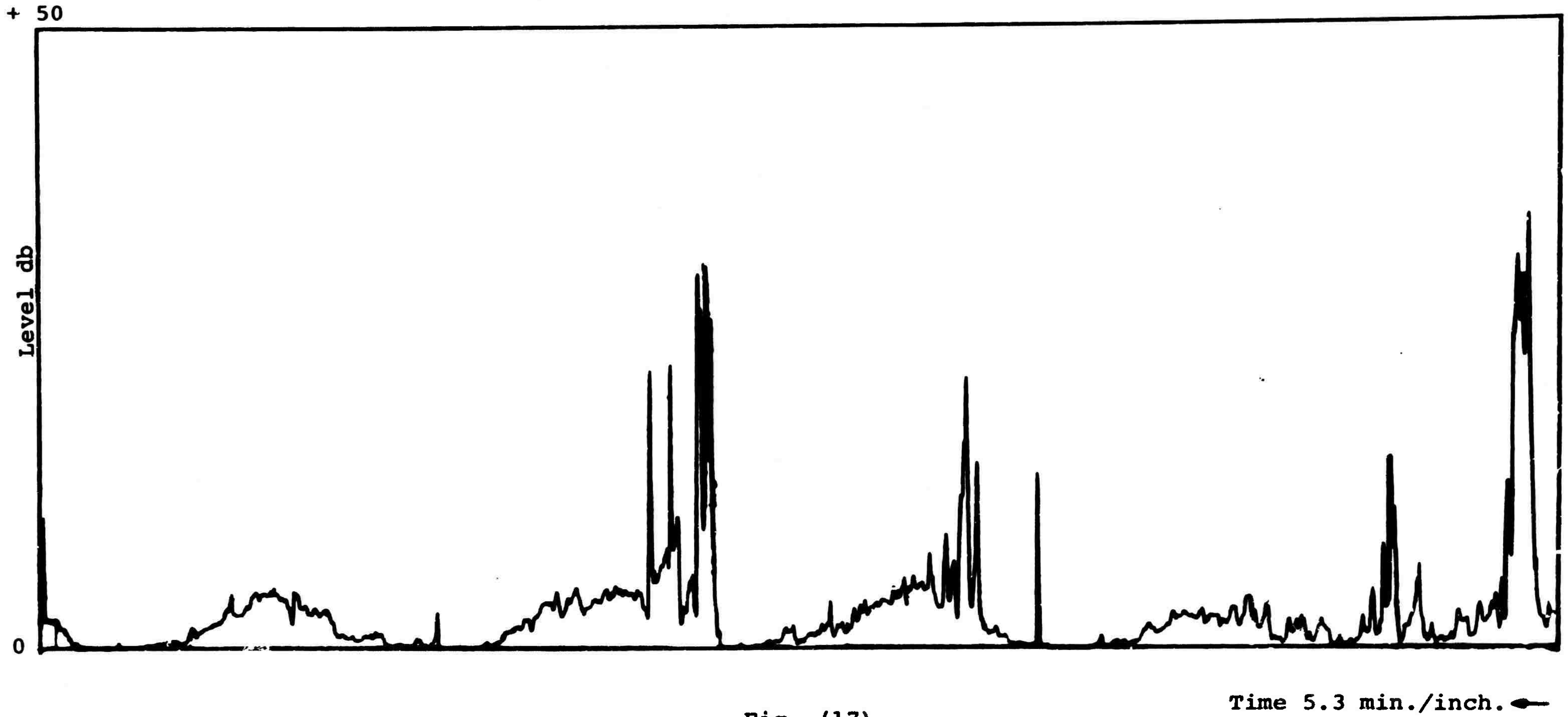


Fig. (17)
Coastal Mariner energy level vs. time.
Center frequency 1 2/8 cps. Band width 1/8 cps.

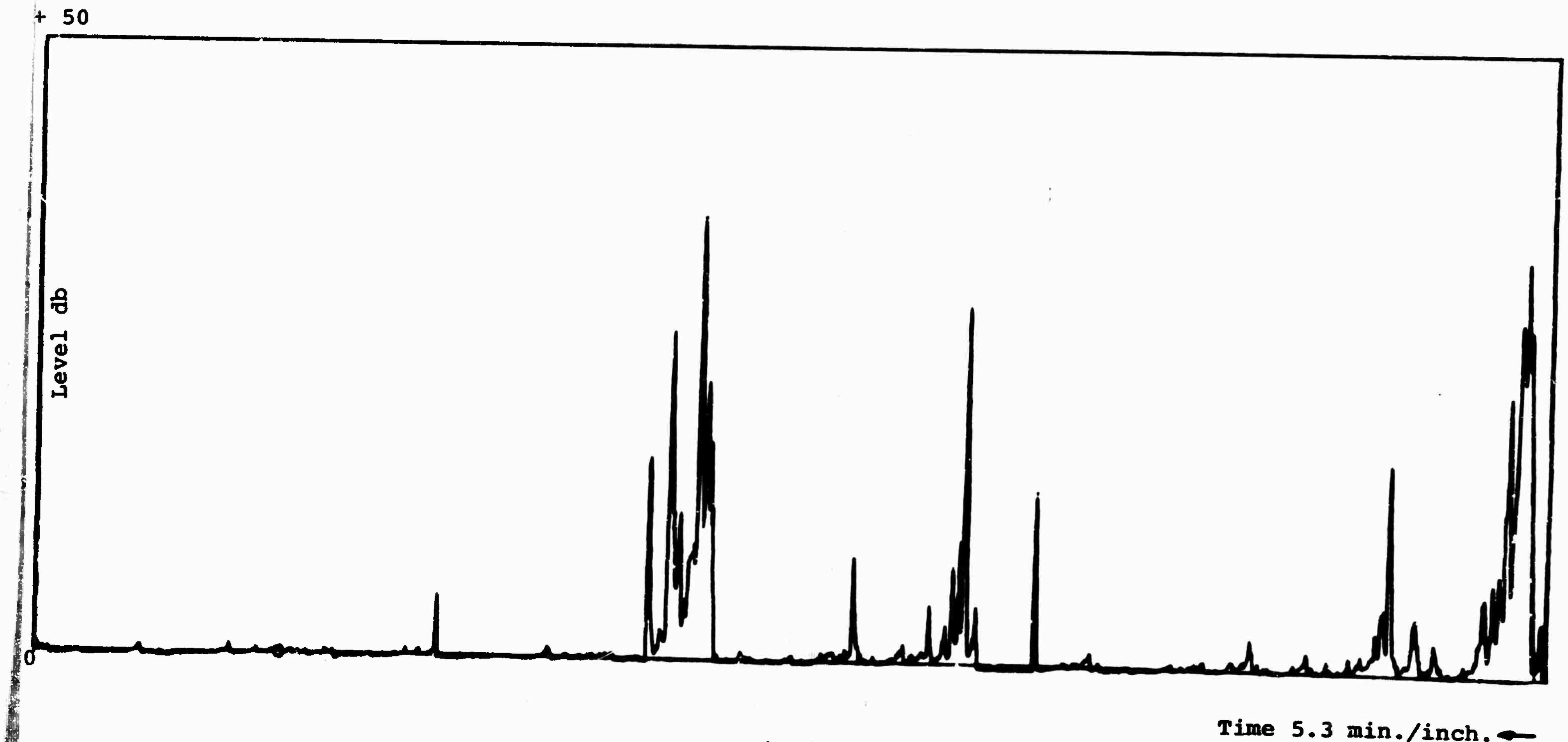


Fig. (18)
Coastal Mariner energy level vs. time.
Center frequency 1 3/8 cps. Band width 1/8 cps.

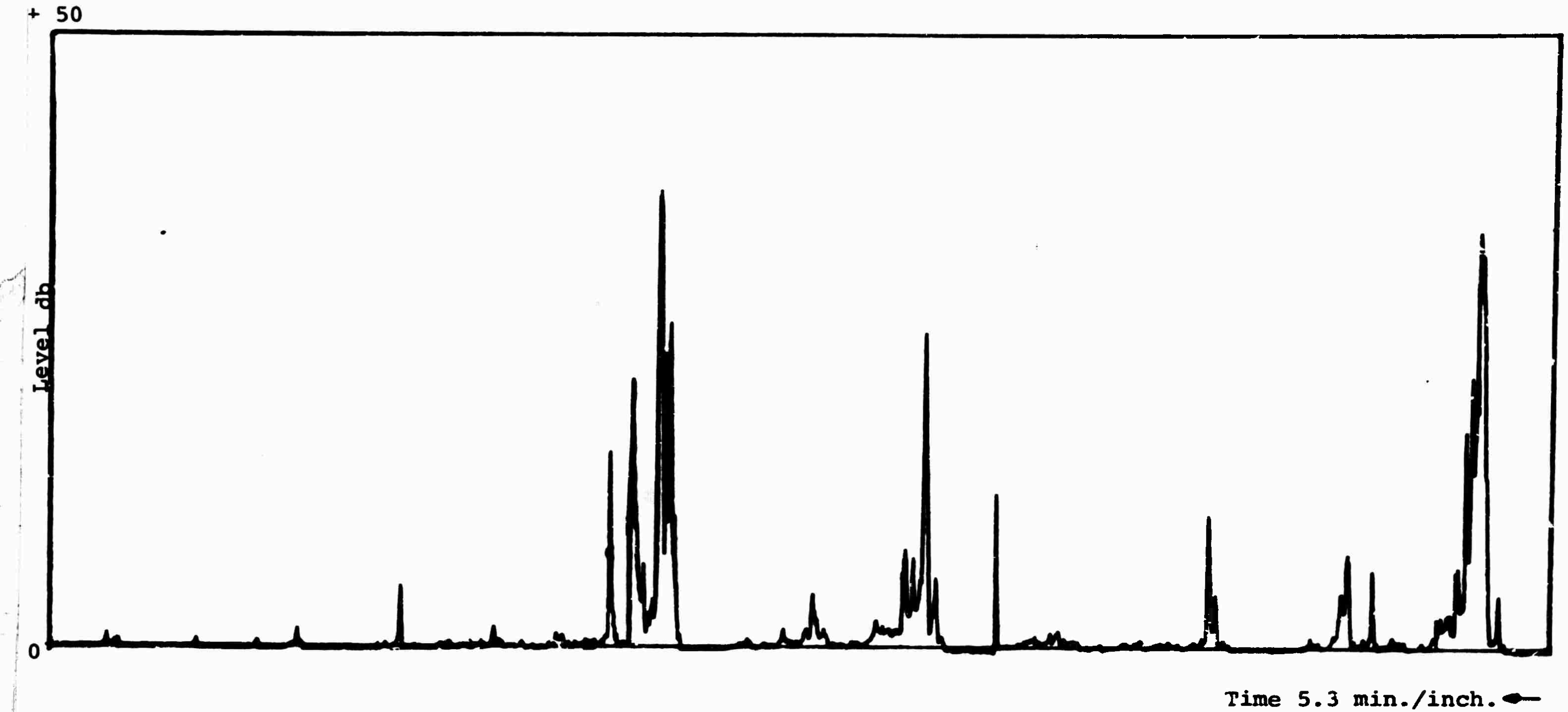


Fig. (19)
Coastal Mariner energy level vs. time.
Center frequency 1 4/8 cps. Band width 1/8 cps.

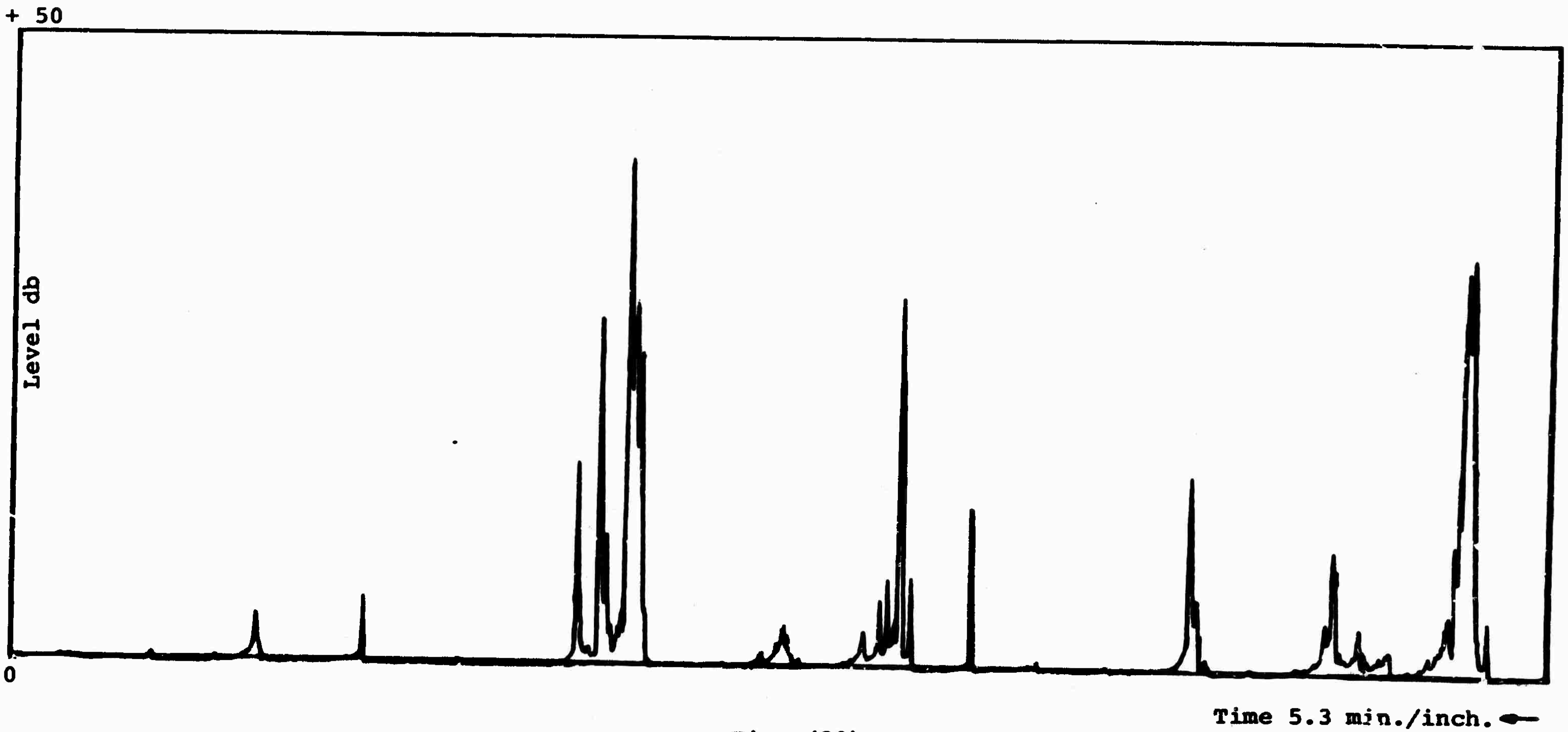


Fig. (20)
Coastal Mariner energy level vs. time.
Center frequency 1 5/8 cps. Band width 1/8 cps.

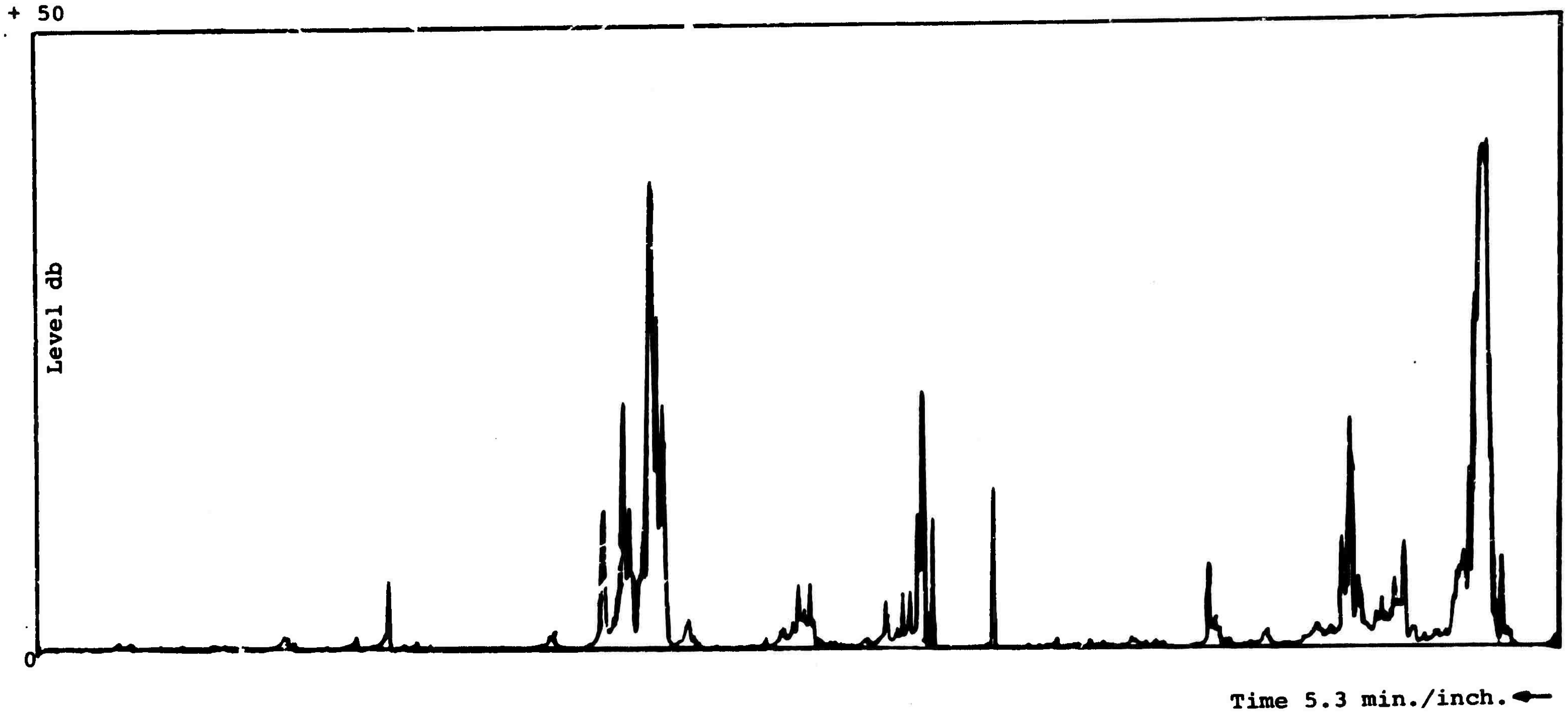


Fig. (21)
Coastal Mariner energy level vs. time.
Center frequency 1 6/8 cps. Band width 1/8 cps.

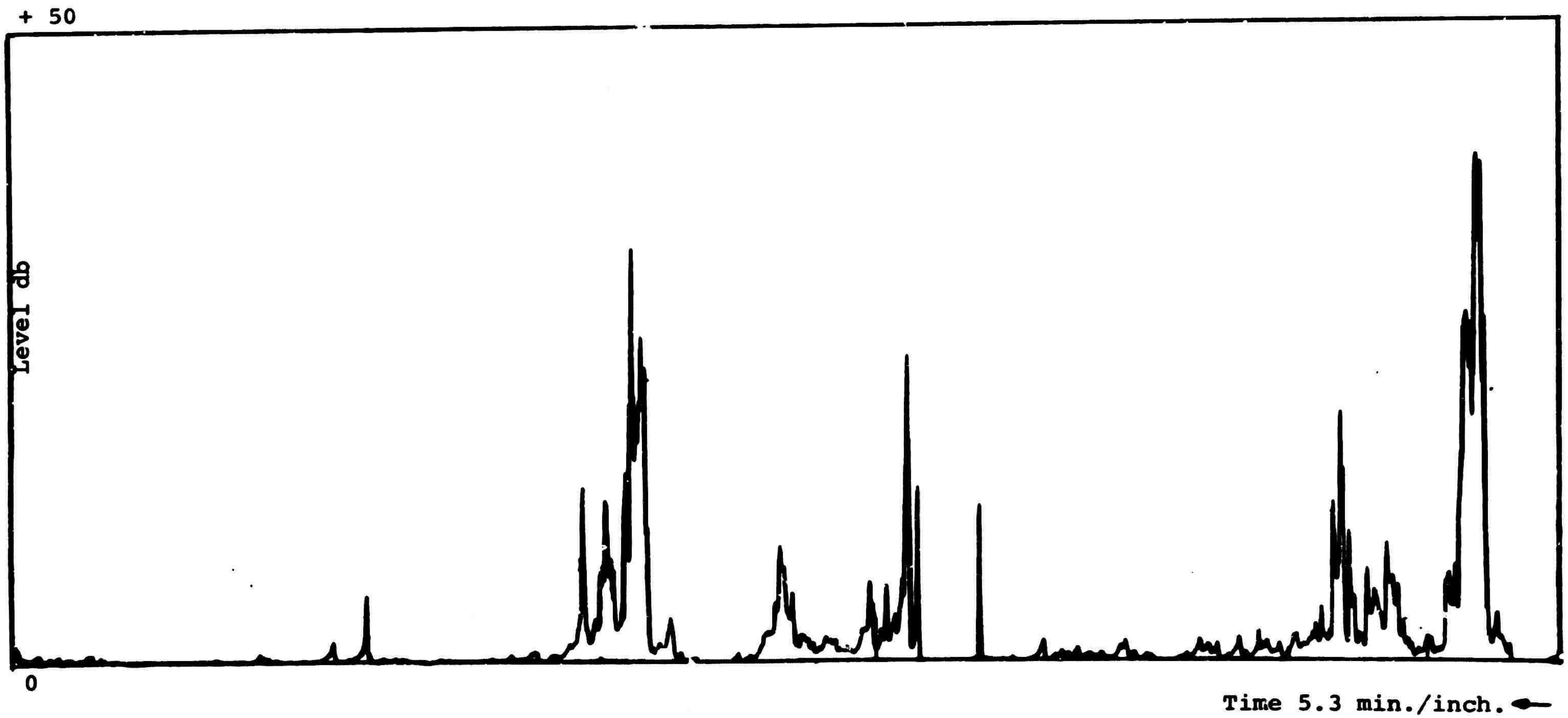


Fig. (22)
Coastal Mariner energy level vs. time.
Center frequency 1 7/8 cps. Band width 1/8 cps.

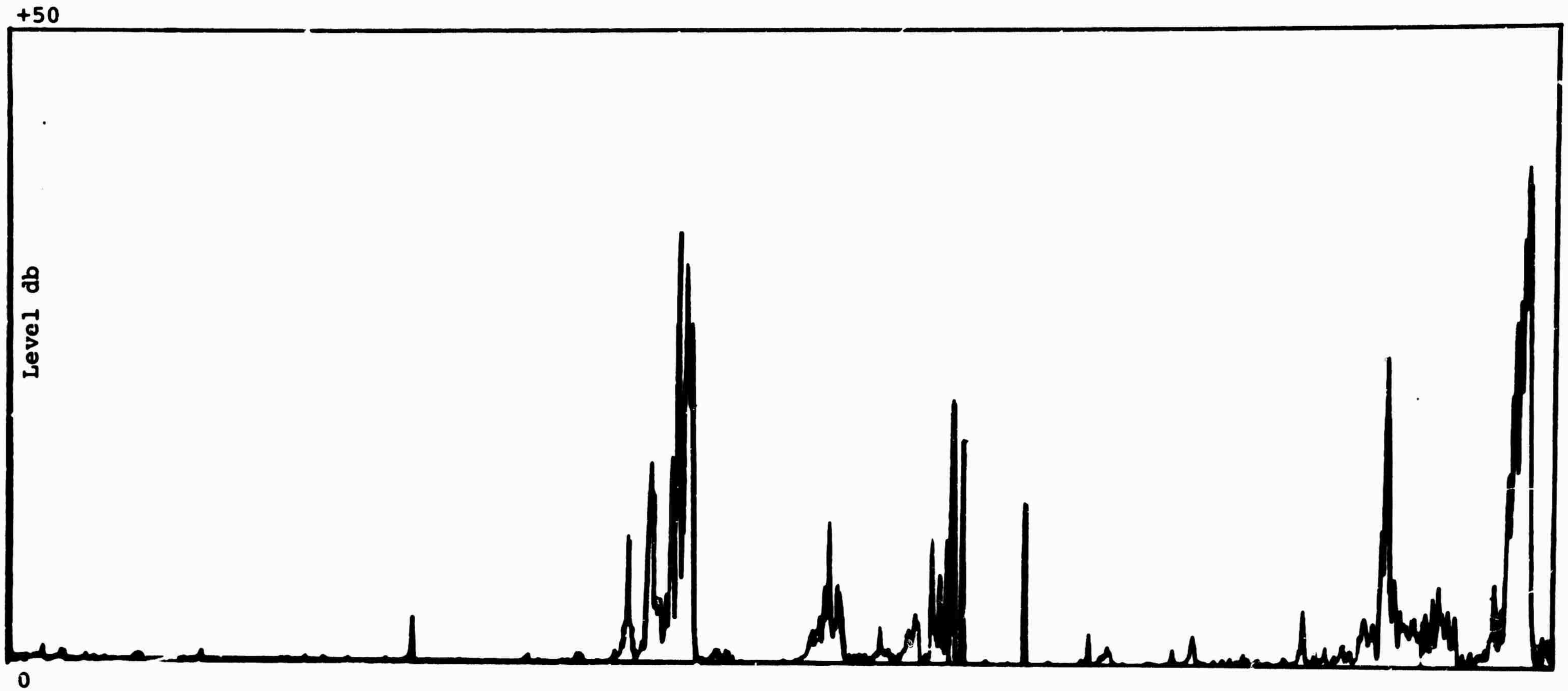


Fig. (23)
Coastal Mariner energy level vs. time.
Center frequency 2 cps. Band width 1/8 cps.

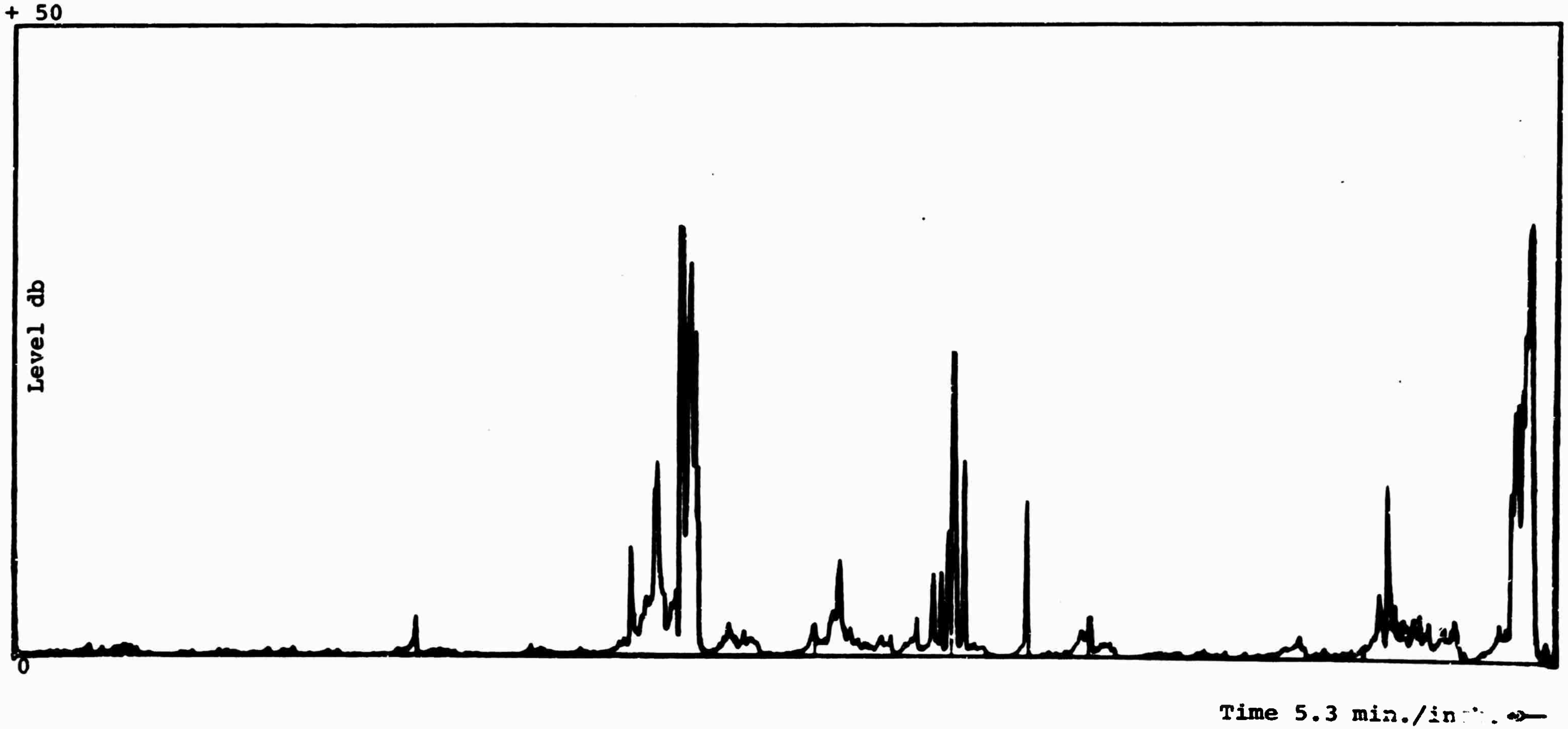


Fig. (24)
Coastal Mariner energy level vs. time.
Center frequency 2 1/8 cps. Band width 1/8 cps.

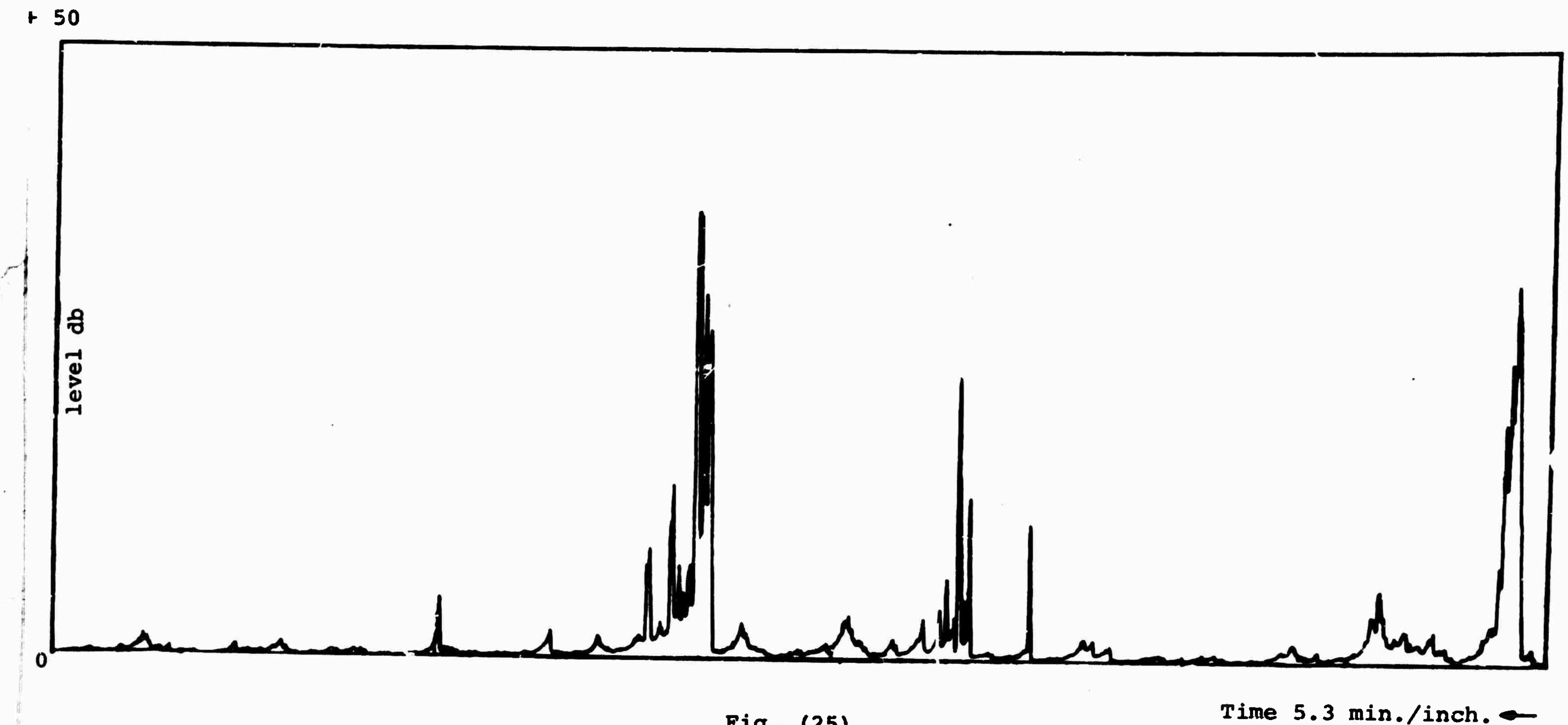


Fig. (25)
Coastal Mariner energy level vs. time.
Center frequency 2 2/8 cps. Band width 1/8 cps.

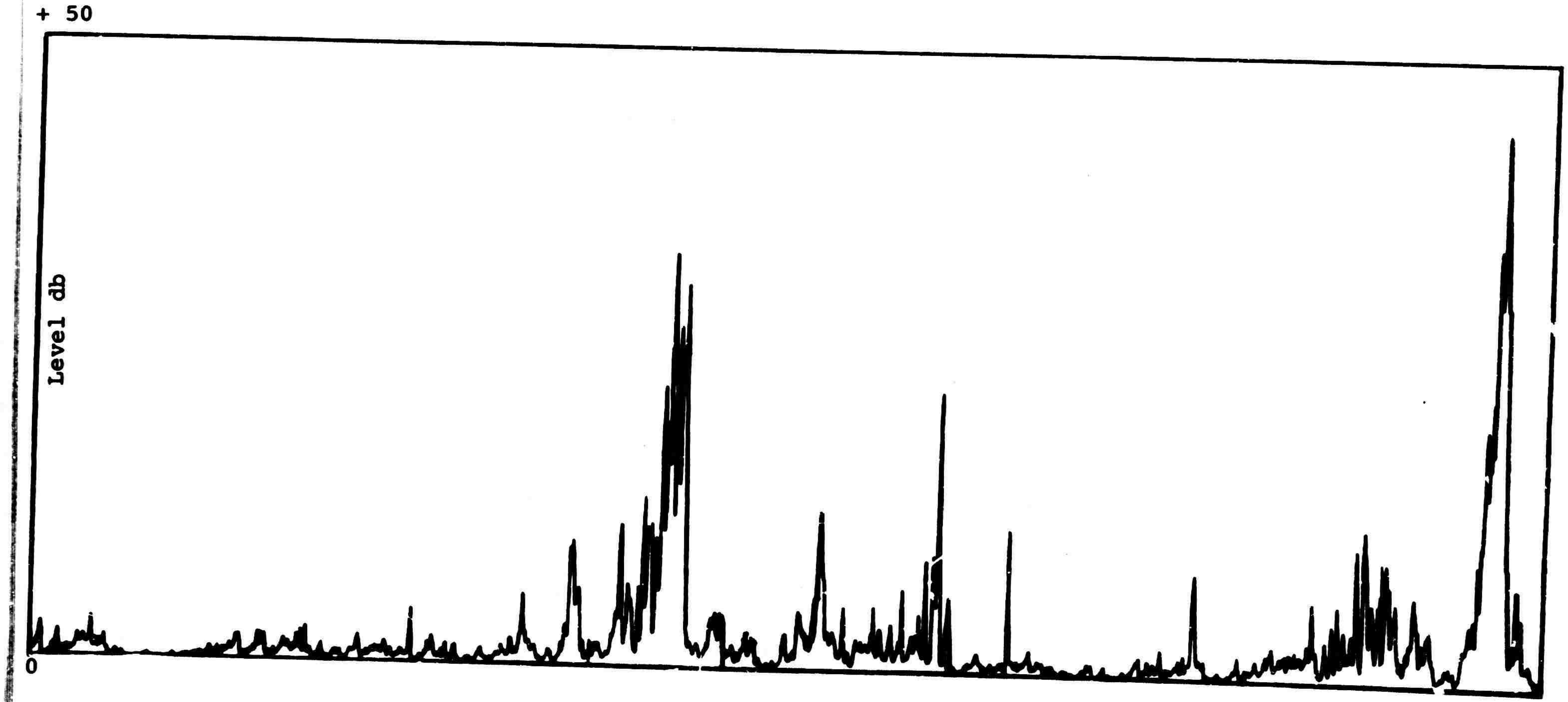


Fig. (2b)
Coastal Mariner energy level vs. time.
Center frequency 2 3/8 cps. Band width 1/8 cps.

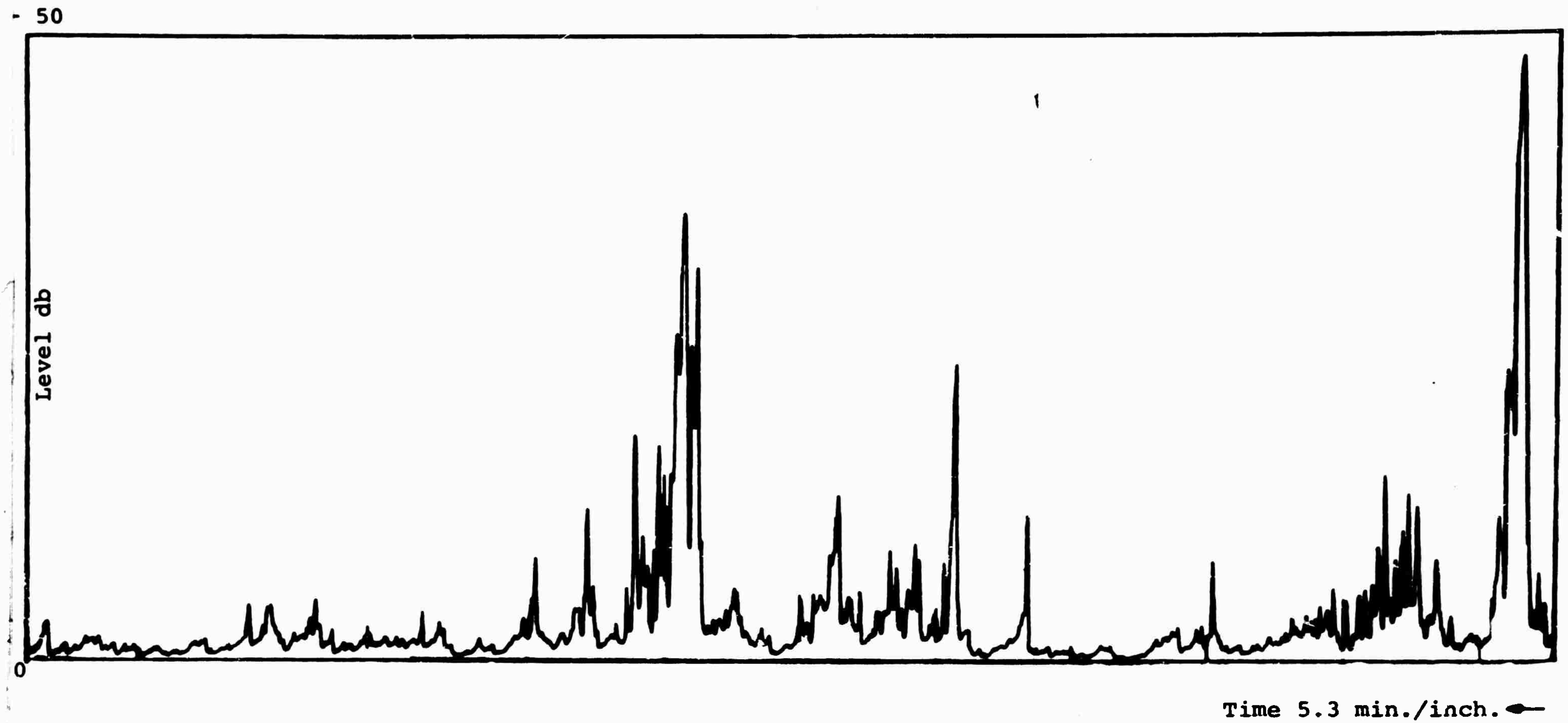


Fig. (27)
Coastal Mariner energy level vs. time.
Center frequency 2 4/8 cps. Band width 1/8 cps.

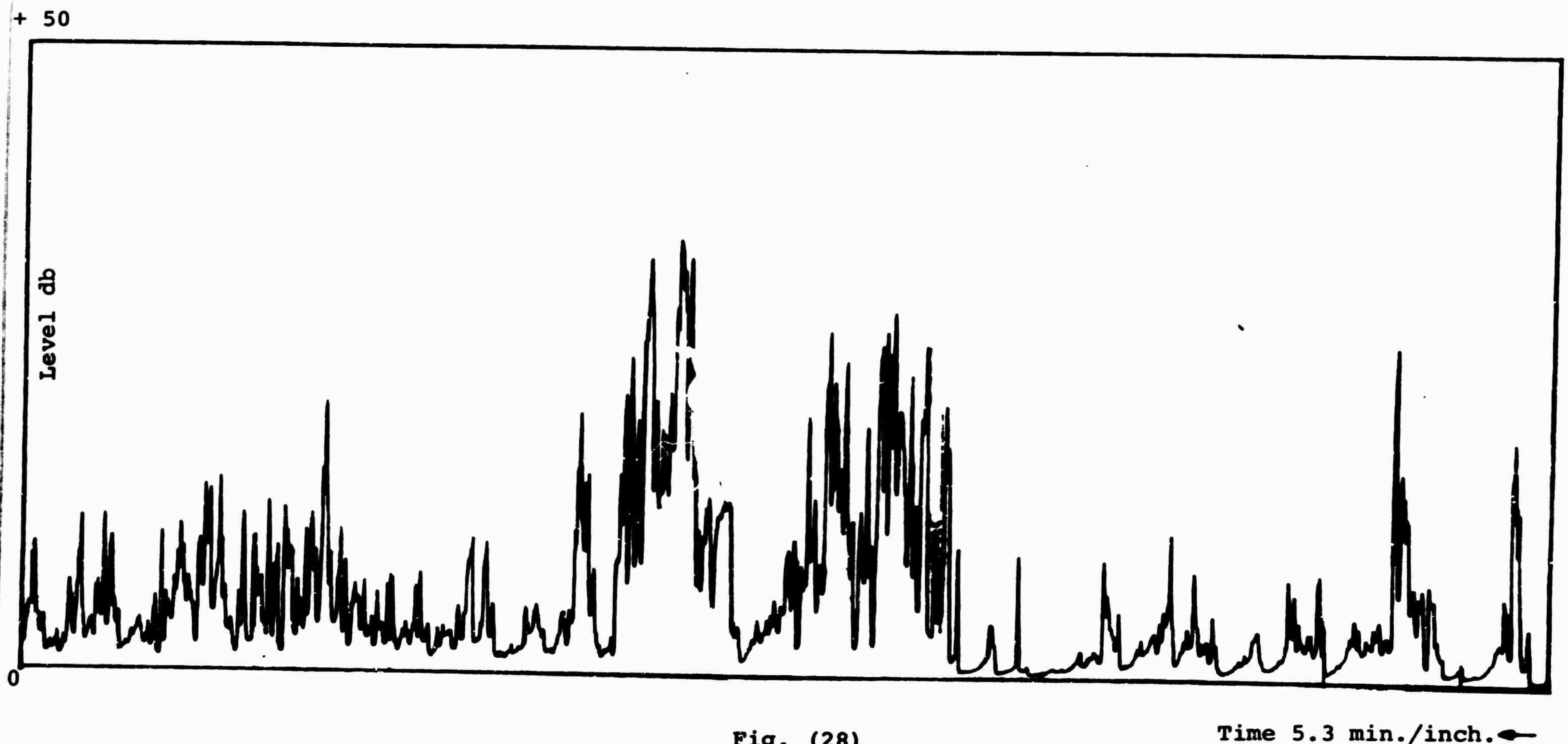
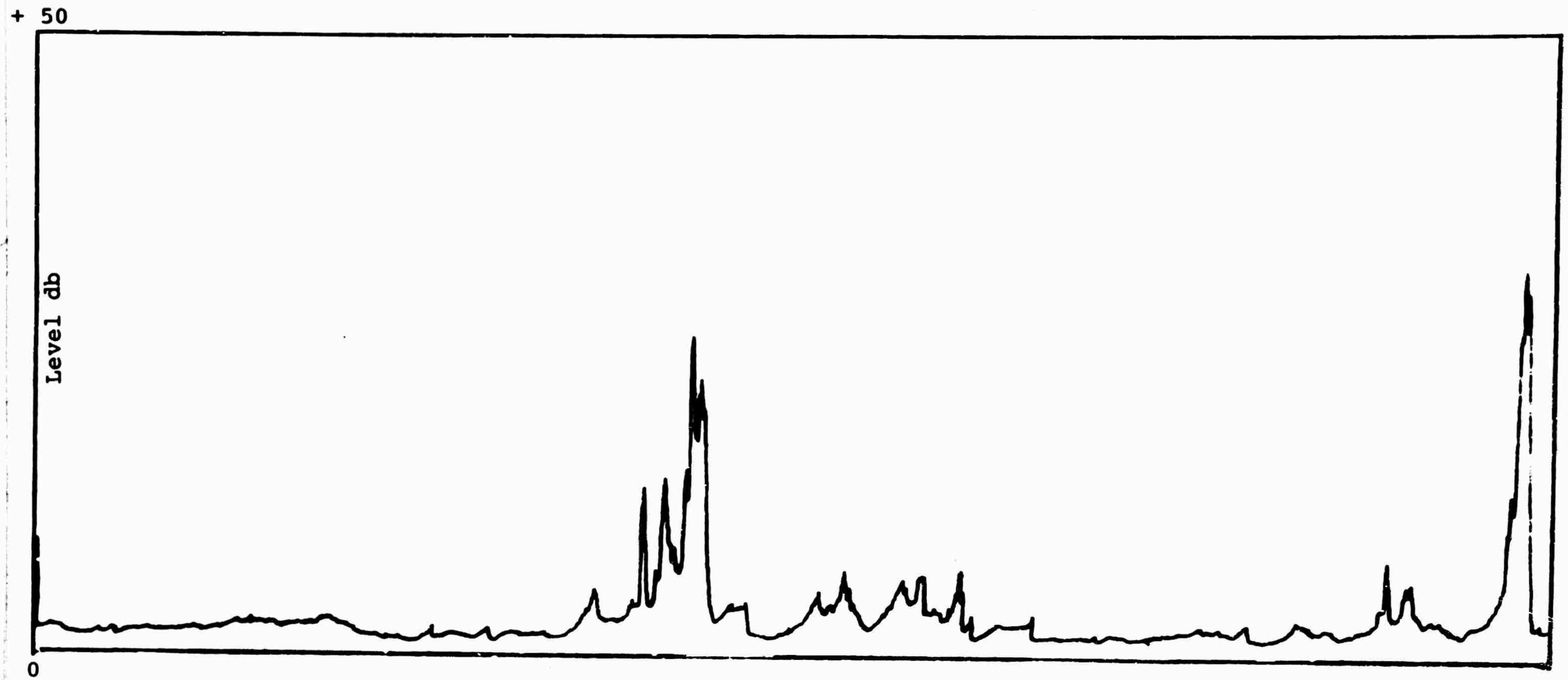


Fig. (28)
Coastal Mariner energy level vs. time.
Center frequency 12 3/16 cps. Band width 1/8 cps.



Time 5.3 min./inch.

Fig. (29)
Coastal Mariner Energy Level vs. Time.
Center Frequency 1 9/16 cps. Band Width 0 - 3 1/8 cps.

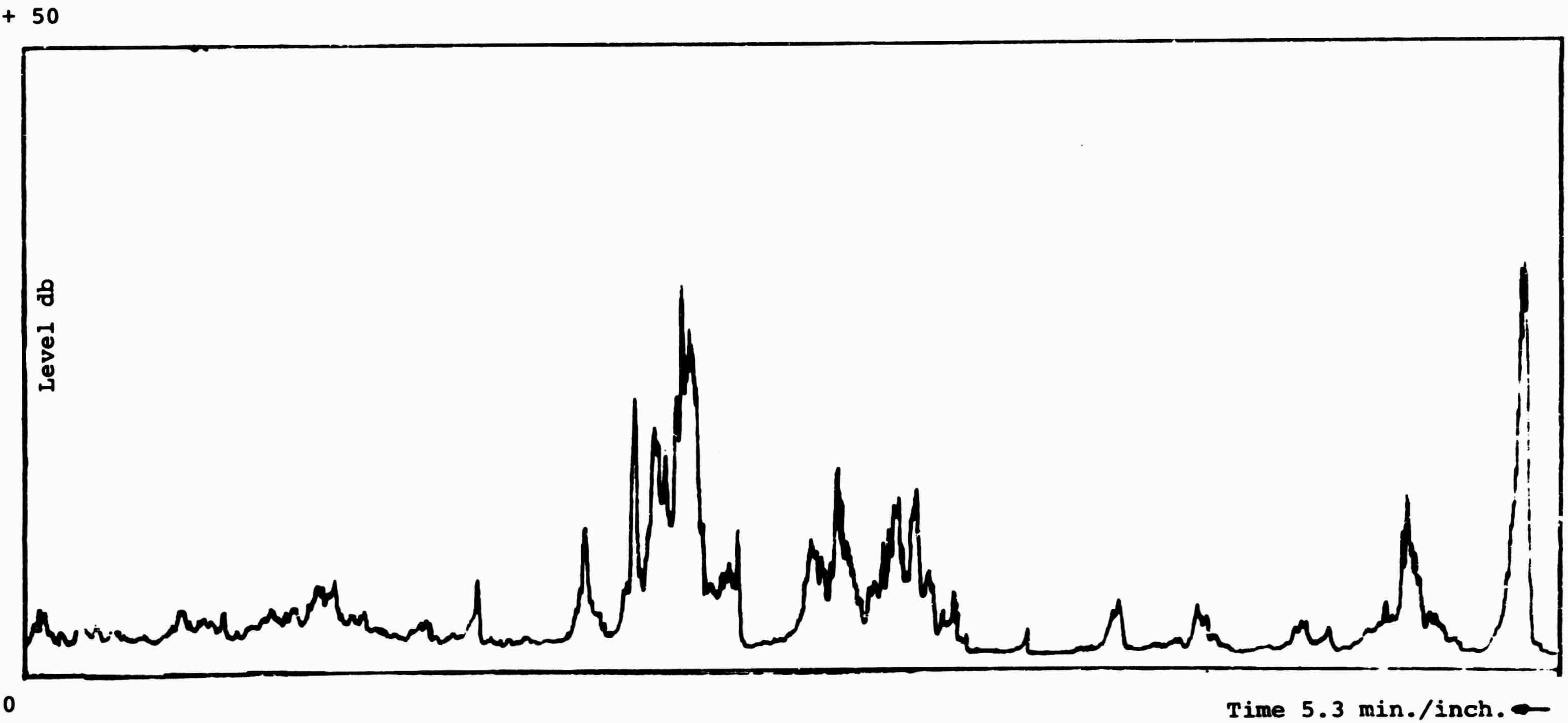


Fig. (30)
Coastal Mariner Energy Level vs. Time.
Center Frequency 4 11/16 cps. Band Width 3 1/8 - 6 1/4 cps.

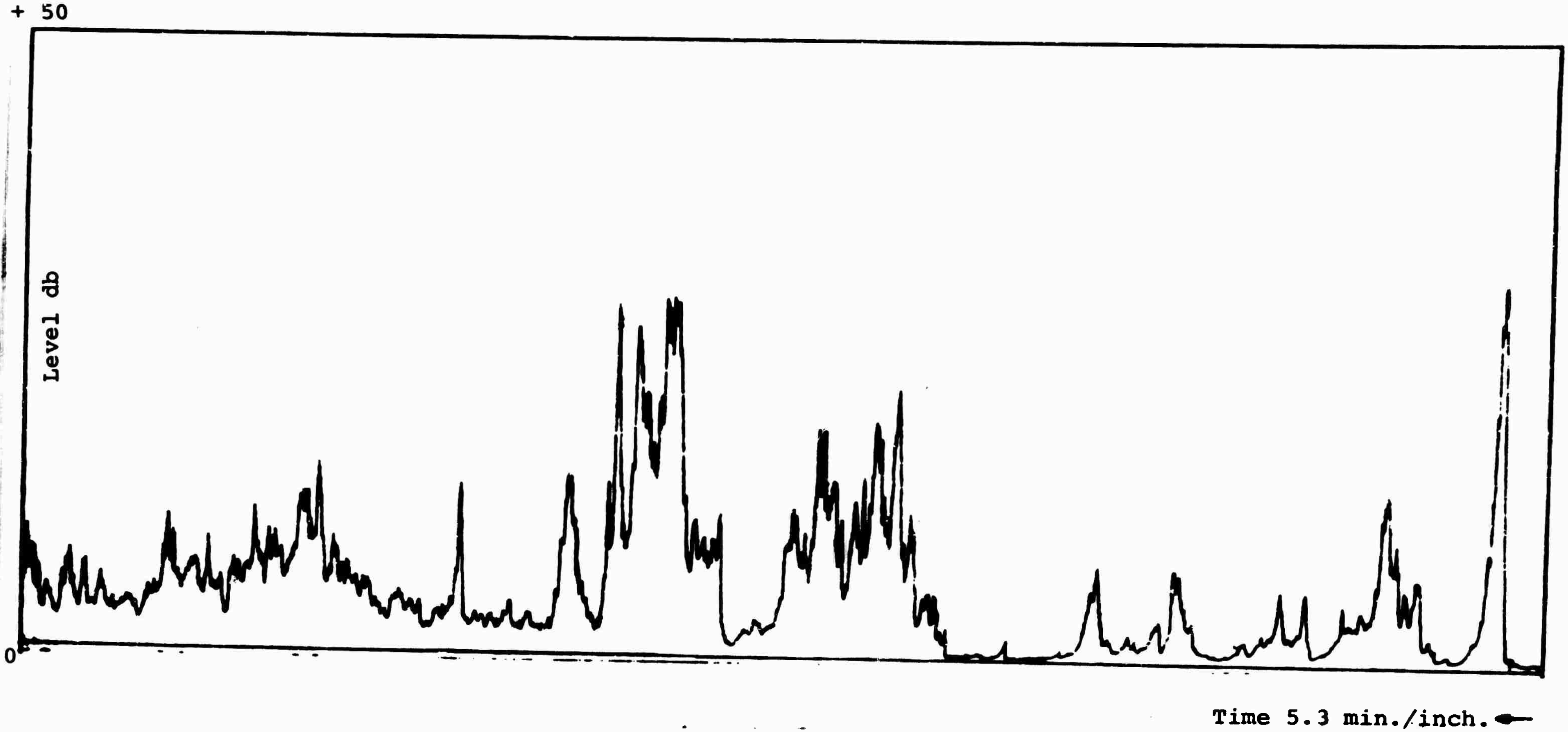


Fig. (31)
Coastal Mariner Energy Level vs. Time.
Center Frequency 7 13/16 cps. Band Width 6 1/4 - 9 3/8 cps.

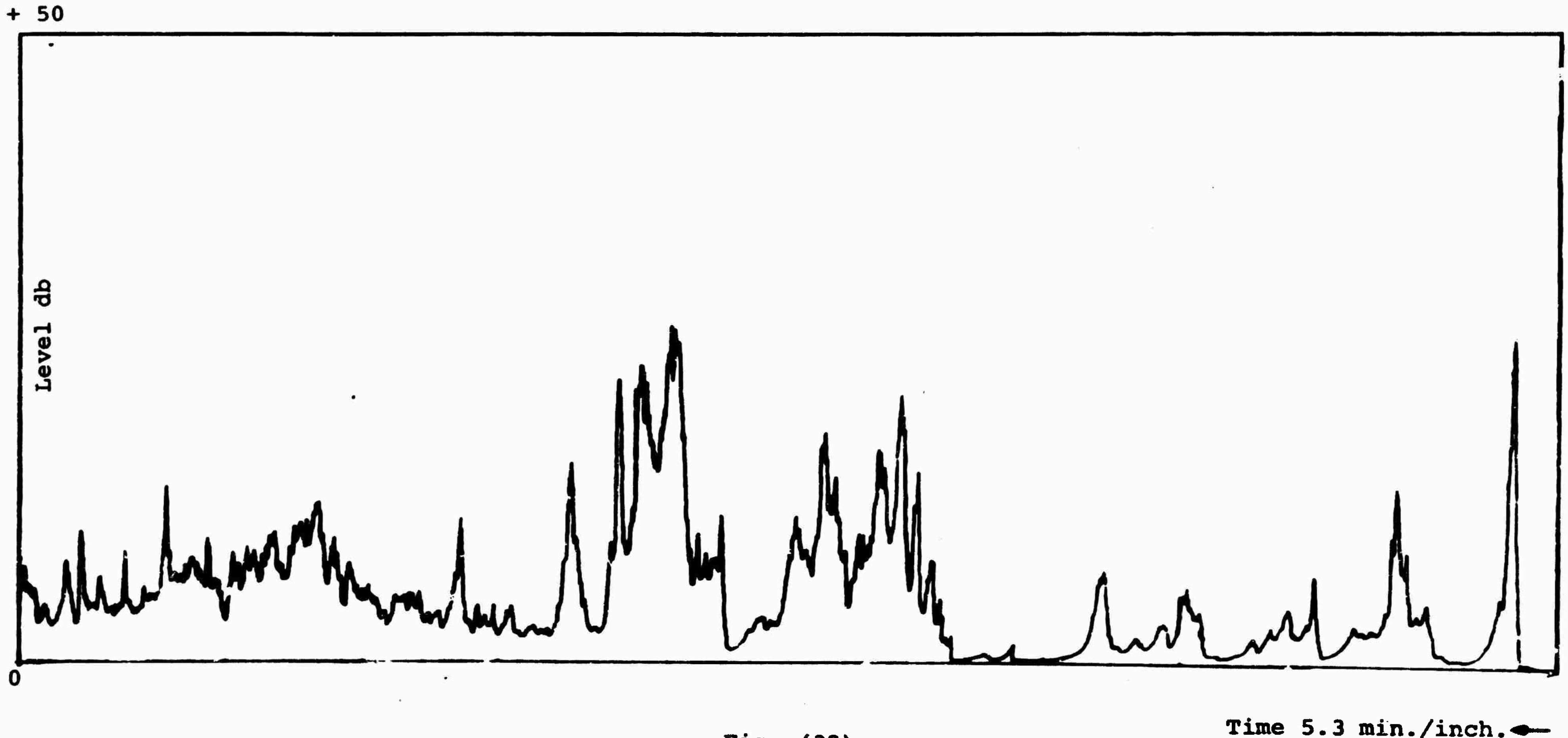


Fig. (32)
Coastal Mariner Energy Level vs. Time.
Center Frequency 10 15/16 cps. Band Width 9 3/8 - 12 1/2 cps.